Hepburn Dune Living Shoreline Project

August 30, 2019

Connecticut Institute for Resilience and Climate Adaptation

Sponsored by a grant from the Connecticut Institute for Resilience and Climate Adaptation (CIRCA). CIRCA is a partnership between the University of Connecticut and the State of Connecticut Department of Energy and Environmental Protection. More information can be found at: www.circa.uconn.edu

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August 30, 2019
GZA File No. 03.0034368.00

Connecticut Institute for Resilience & Climate Adaptation (CIRCA)
University of Connecticut
Avery Point Campus
1080 Shennecossett Road
Groton, Connecticut 06340

Re: Final Report for Municipal Grant Close-out
Hepburn Dune and Marsh Preservation Living Shoreline Project
Borough of Fenwick, Old Saybrook, CT

Dear Professor O'Donnell:

GZA GeoEnvironmental, Inc. (GZA), on behalf of the Borough of Fenwick, Old Saybrook, Connecticut, is pleased to submit this Final Report for the close-out of the Municipal Grant that was awarded to the Hepburn Dune and Marsh Preservation Project in December 2017.

We appreciate CIRCA's support and the opportunity to advance this project to final design with the awarded grant. We also hope that this project will contribute to the state of practice for Living Shorelines in Connecticut.

Please contact Daniel Stapleton via phone at (781) 278-5743 or via email at daniel.stapleton@gza.com with comments and questions.

Very truly yours,
GZA GEOENVIRONMENTAL, INC.

Hande McCaw, P.E $^{FL, MA}$
Senior Project Manager/Coastal Engineer

Stephen Lecco
Consultant/Reviewer

Daniel C. Stapleton, P.E.
Senior Principal

Attachments

Executive Summary

The Hepburn Dune and Marsh Preservation Living Shoreline Project is a proposed shoreline stabilization project using a Living Shoreline to mitigate shoreline erosion. The project is located on the Long Island Sound coastline in the Borough of Fenwick in Old Saybrook, Connecticut. The project site is a 450-linear foot segment of coastline consisting of a short, narrow barrier spit that separates the Sound from Lynde Point Marsh, a restored tidal marsh. Chronic and episodic erosive shoreline change has been an on-going issue at the project site. The Borough has expended significant effort and cost to restore the tidal marsh and stabilize the shoreline during the last 10 to 15 years. Shoreline erosion, however, continues.

The goal of the project is to stabilize the long-term shoreline erosion and mitigate the potential for a breach of the barrier spit. The selected shoreline stabilization method is a Living Shoreline constructed consistent with current Connecticut Living Shoreline guidance. Project components include:

1. Relocation of a portion of Crab Creek involving: a) excavation of new tidal channel; b) removal of the temporary corrugated pipe placed by the DEEP; and c) backfill of the former section of re-aligned channel (using the excavation backfill). Construction of a new channel culvert is also under consideration.
2. Beach nourishment and planting to construct a new dune that is wider and higher than the former dune, but will be consistent with the more robust dunes abutting the project site to the east.
3. Construction of new rock sills placed on an offset, staggered layout with a cuspate alignment consistent with the current project shoreline shape. The purposes of the rock sills are to: a) stabilize the seaward margin of the new Living Shoreline marsh; b) attenuate wave energy during prevailing wave conditions, to support mash survivability; and c) within practical and cost limitations, attenuate wave energy during coastal storm events to minimize the amount of marsh stem breakage (and to a lesser extent, minimize dune erosion).
4. Relocation of existing cobbles within the intertidal zone (within areas to be filled to create new marsh) and placement of these cobbles within the beach. (The existing beach has a high cobble content. The goal is to enhance the existing beach as a cobble beach).
5. Placement of sand fill within the intertidal zone (to the rock sills), with marsh planting to create a new Living Shoreline marsh.

The project methodology utilized “state-of-the-practice” engineering including: 1) metocean data analysis including statistical analysis of wind/wave conditions; 2) numerical wave modeling; 3) estimation of wave attenuation and bottom stress; and 4) comparison of model output to empirical and semi-empirical performance criteria developed in the literature.

The small physical size of the project, the challenging wave environment and the commitment of the project stakeholders toward maintenance of the marsh and beach over the long term makes this project an excellent pilot project, consistent with CIRCA’s mission and objectives.

PROJECT BACKGROUND AND CONTEXT

Figure 1. Project Location

The Hepburn Dune and Marsh Preservation Living Shoreline Project is a proposed shoreline stabilization project using a Living Shoreline to mitigate shoreline erosion. The project is located on the Long Island Sound coastline in the Borough of Fenwick in Old Saybrook, Connecticut. The project site is a 450-linear foot segment of coastline on the Long Island Sound located just east of the estate formerly owned by Katherine Hepburn. The project site consists of a short, narrow barrier spit that separates the Sound from Lynde Point Marsh, a restored tidal marsh.

Chronic and episodic erosive shoreline change has been an on-going issue at the project site. The Borough has expended significant effort and cost to restore the tidal marsh and stabilize the shoreline during the last 10 to 15 years. Shoreline erosion, however, continues. The proximity of the eroded shoreline, which is now close to the tidal marsh and Crab Creek increases the likelihood that the remaining sand spit will be breached during future coastal storms. Crab Creek is a tidal channel within the marsh that is hydraulically connected with South Cove to the north and a tidal pond to the southwest. Unrepaired breach of the barrier spit could have negative consequences for both improved property in the area and the restored tidal marsh and creek located inland of the barrier spit. Future breaches will also require periodic maintenance to excavate overwash sand from Crab Creek and associated costs. During the Winter 2018/2019, a coastal storm caused significant dune erosion, overwash and near-breach event that deposited sediment within Crab Creek requiring emergency response by the Connecticut DEEP.

The goal of the project is to stabilize the long-term shoreline erosion and mitigate the potential for a breach of the barrier spit. The selected shoreline stabilization method is a Living Shoreline constructed consistent with current Connecticut Living Shoreline guidance. As part of the project permitting, GZA completed an alternatives analysis which presents shoreline stabilization alternatives ranging from beach nourishment to a hybrid Living shoreline with hard coastal structure to a Living Shoreline consistent with current Connecticut guidance. The alternatives analysis is provided to CIRCA under separate cover. The Borough received grants from the Connecticut Institute for Resilience &

Climate Adaptation (CIRCA) to design the Living Shoreline. After Winter 2018/2019, the project was expanded to include re-alignment of a portion of Crab Creek (possibly including construction of a new culvert connecting the creek to the tidal pond). The Borough received additional funding from the Long Island Sound Futures Fund (LISFF).

Background

During 2004 to 2006, the Lynde Point Marsh (located inland of the project site – see **Figure 1**) was restored by the Borough in partnership with the Connecticut DEEP Wetlands Restoration Unit and other partners. The project restored 10 acres of tidal wetland through the removal of 60,000 cubic yards of dredge sediment placed within the former tidal marsh during the 1940's which converted the tidal wetlands to non-tidal uplands and were subsequently inundated with phragmites. Removal of dredge sediment as a part of the marsh restoration project returned the area to tidal wetlands, open water, panne and brackish meadow habitats that are beneficial to migratory waterfowl, wading birds, shorebirds and nesting passerines. The marsh restoration project improved habitat for federally endangered shortnose sturgeon and the state threatened Atlantic sturgeon. Other species to benefit from this project included the bald eagle, northern harrier, northern diamondback terrapin, seaside and saltmarsh sharp-tailed sparrow, and wilet and glossy ibis.

The barrier spit separating the marsh and tidal creek has been experiencing long-term shoreline erosion and the width of the spit is narrow and vulnerable to breach during a coastal storm event. Review of historic photographs and shoreline change data indicates that the shoreline erosion is due, in part, to the construction of coastal structures, including groins and breakwaters, within sand updrift locations. A breach would have negative consequences for both improved property in the area and the recently restored tidal marsh and creek located inland of the barrier spit. A breach in the barrier spit would potentially result in: 1) creation of a tidal inlet, open to Long Island Sound; 2) erosion of the tidal marsh and creek; 3) change in the salinity of the marsh, resulting in ecological impact; and 4) damage to improved property including the existing drainage culvert (under Mohegan Avenue), the roadway, and both developed and undeveloped property (Hepburn Estate). A permanent breach of the barrier spit would result in significant change to the nature of the southern shoreline of Fenwick.

In an attempt to stabilize the barrier spit and dune, a reinforced dune was constructed in 2007 using Filtrex sand-filled tubes and imported sand (see **Figure 2**). The reinforced dune was planted in 2008 with American beach grass and switch grass, which became well-established. However, Hurricane Irene and subsequently Superstorm Sandy completely eroded the reinforced dune, destroyed the sand tubes and deposited overwash sand in the backwater marsh and creek (see **Figure 3**).

Figure 2. 2007 – 2008 Dune Restoration Project (project undertaken by others)

Figure 3. Site Conditions during Tropical Storm Irene (background), Eroded Dune Post-Irene (top right)

During April of 2017, The Borough contacted Mr. Peter Francis, the Supervising Environmental Analyst in the Coastal Resources Section of the Land & Water Resources Division of the Connecticut DEEP, who suggested a Living Shoreline approach to dune and marsh protection. The Living Shoreline approach suggested by Mr. Francis included dune restoration, beach sand placement, coir logs, new marsh, stone sills and wave attenuation structures.

The Borough contracted with GZA to: 1) evaluate the existing conditions at the site; and 2) develop shoreline stabilization alternatives (preferably using a Living Shoreline approach). During 2017, GZA assisted the Borough with

a successful grant application with the Connecticut Institute for Resilience & Climate Adaptation (CIRCA) to assist with funding for final engineering and design. As part of the grant, the project, if undertaken, will be used as a case study for constructing a Living Shoreline in Connecticut.

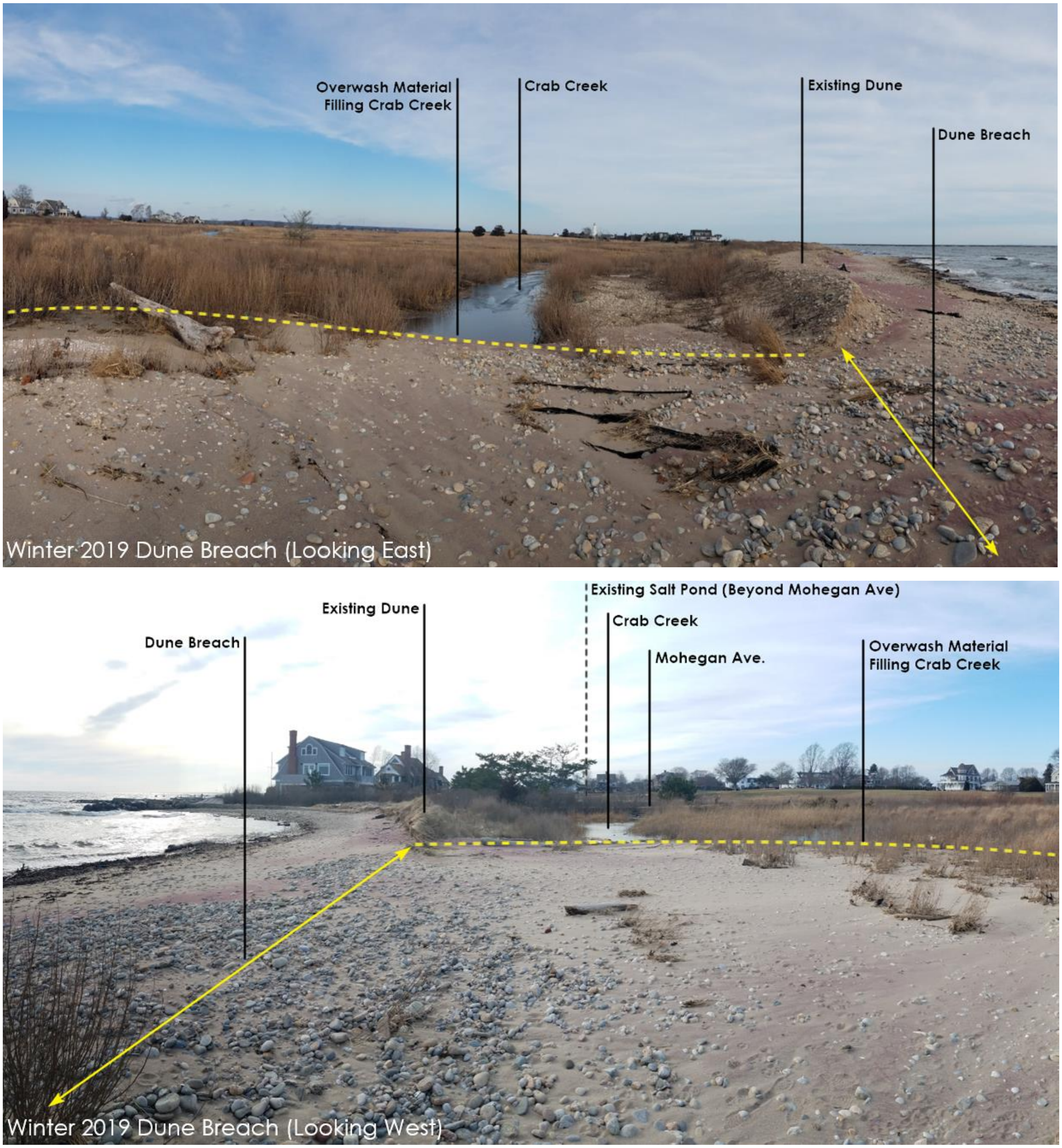


Figure 4. Site Conditions after 2019 Winter Storm, Looking East (Top), Looking West (Bottom)

During the winter of 2019, storm activity led to a breach in the dune with overwash material filling the adjacent Crab Creek (see **Figure 4**). With the tidal creek filled, the adjacent salt pond west of Mohegan Avenue has been slow to drain following rain events leading to increased water elevations in the pond. The Borough of Fenwick worked with DEEP's Wetland Restoration Unit to respond to this situation. The emergency response plan included: 1) excavating the overwash material from the creek and depositing this material within the original dune footprint; 2) installing a temporary 36-inch diameter corrugated pipe within the section of the creek previously filled to maintain tidal connection in case of future breaches; and 3) anchoring drift trees within the footprint of the dune breach to provide some protection from future storm activity. This response was considered to be a temporary measure.

After the winter 2019 dune breach, the Borough decided to expand the project limits landward to include relocating Crab Creek landward (and possibly constructing a new culvert) to allow room for construction and natural migration of the dune.

PROJECT GOALS, DESCRIPTION AND METHODS

Goal

The goal of the project is stabilize the shoreline and mitigate the potential for a breach of the barrier spit using a Living Shoreline approach as defined by the State of Connecticut. Living Shorelines are nature-based erosion control techniques, relatively new to Connecticut and an alternative to hard coastal structures (e.g., breakwaters, revetments). Per CIRCA… "Living shorelines mimic natural settings and have many positive co-benefits to erosion control, including but not limited to: habitat creation, water quality enhancement, and maintaining natural coastal processes."

There are several challenges to achieving this goal:

1. The high wave energy present along Connecticut Long Island Sound shorelines. The open Sound fetch results in: a) prevailing wave conditions resulting in high frequency waves with heights greater than those associated with marsh survivability; and b) large waves and storm surge during coastal storms (tropical depressions and cyclones and extratropical nor'easters). These conditions significantly challenge nature-based systems (as evidenced by the frequent failure of these systems).
2. The presence of existing coastal structures abutting the project site to the west. These structures: a) prevent longshore sediment transport to the project site; and b) result in wave refraction, altering the natural currents at the project site. Both of these conditions contribute significantly to the observed shoreline erosion and require consideration when placing new elements (i.e., the proposed Living Shoreline) within the area.
3. The potential for negative outcomes and the intent when designing the new Living Shoreline features to avoid constructing elements that will cause new shoreline erosion to the east of the project site.
4. Sea level rise, including the increasing rate of sea level change. Sea level rise challenges the project due to increase in water level and wave height. Also, there is no natural source of sand available for marsh accretion as required to respond to sea level changes.

Project Description

The Hepburn Dune and Marsh Preservation Living Shoreline Project includes a restored and vegetated dune, a cobble beach, intertidal sand fill with low marsh (spartina alterniflora) plantings and low profile nearshore sills. The project also includes relocating Crab Creek (and possibly the culvert that connects it to the tidal pond) landward of the formerly Hepburn Estate (see plan in **Attachment A**). Project components include:

1. Relocation of a portion of Crab Creek involving: a) excavation of new tidal channel; b) removal of the temporary corrugated pipe placed by the DEEP; and c) backfill of the former section of re-aligned channel (using the excavation backfill). Construction of a new channel culvert is also under consideration.
2. Beach nourishment and planting to construct a new dune that is wider and higher than the former dune, but will be consistent with the more robust dunes abutting the project site to the east.
3. Construction of new rock sills placed on an offset, staggered layout with a cuspate alignment consistent with the current project shoreline shape. The purposes of the rock sills are to: a) stabilize the seaward margin of the new Living Shoreline marsh; b) attenuate wave energy during prevailing wave conditions, to support mash survivability; and c) within practical and cost limitations, attenuate wave energy during coastal storm events to minimize the amount of marsh stem breakage (and to a lesser extent, minimize dune erosion).
4. Relocation of existing cobbles within the intertidal zone (within areas to be filled to create new marsh) and placement of these cobbles within the beach. (The existing beach has a high cobble content. The goal is to enhance the existing beach as a cobble beach).
5. Placement of sand fill within the intertidal zone (to the rock sills), with marsh planting to create a new Living Shoreline marsh.

Methods

A key benefit of this project relative to CIRCA's mission is the development of a Living Shoreline engineering and design methodology that is efficient, well-suited to the Long Island Sound climatology and based on physics (rather than being completely based on empirical approaches (i.e., "trial and error"). While Living Shoreline technical guidance exists (e.g., Stevens Institute), much of the existing guidance was developed for areas like the Chesapeake Bay that have a less energetic environment than Long Island Sound. CIRCA and the University of Connecticut started that process through the implementation of a physics-based screening tool. This project developed and utilized a methodology that is consistent with the approach used by that screening tool, but is more technically-robust.

The other critical aspect to the methodology used for this project is the application of a risk-based approach which ties project performance to environmental conditions that are characterized by probability of occurrence. While true for all structures, a risk-based approach is particularly important for Living Shorelines and other nature-based features since their performance capability (e.g., survivability) is rarely considered during design, not well understand by owners and regulators, and often may not justify their construction and maintenance costs in a benefit-cost context.

While a risk-based design basis was not explicitly developed for this project, certain performance goals were established for guidance informing design of the project elements, including:

- Survivability of the new Living Shoreline marsh under conditions associated with floods with a recurrence interval of 10-years or less (that is, floods with an annual recurrence interval greater than 10 years may significantly damage the new marsh).
- Minimal beach erosion under conditions associated with floods with a recurrence interval of 5-year recurrence interval or less (that is, floods with an annual recurrence interval greater than 5 years may significantly erode the beach).
- Minimal dune erosion under conditions associated with floods with a recurrence interval of 5-years (that is, floods with an annual recurrence interval greater than 5-years may significantly erode the dune).
- Reduction of the likelihood of a barrier spit breach, at least to the conditions associated with floods with a recurrence interval of 20-years or less (that is, floods with a recurrence interval greater than 20 years may result in a breach).
- Reduction of the observed, on-going shoreline erosion rates at the project site.
- Avoid negative impacts, such as increased erosion and/or shoreline change, in areas outside of the project site.

Not all of these goals will be achievable with the proposed design, given the broader goal of utilizing a nature-based approach that limits the use of coastal structures (and in part due to modifications to the design that occurs during regulatory review). Regardless, they provide a baseline for consideration during design.

The basic methodology used by GZA for the project design included:

1. Statistical analysis of the wind/wave climatology of the project site. GZA performed statistical analysis of 6-minute, averaged 1 to 2 minute sustained, 10-meter wind data available at the New London airport. The wind data was converted to wave heights for multiple fetches and directions using simple, analytical wave calculations (depth, fetch and duration-limited waves). The purpose of this step was to establish the directional wave density and define the existing wave height representative of the prevailing conditions. This wave height (20 percent exceedance probability) is compared to a semi-empirical maximum wave height associated with marsh repetitive stress and survivability.
2. Very high resolution numerical wave modeling of existing conditions using the Simulating Waves in Nearshore (SWAN) model for the prevailing condition and multiple recurrence intervals (up to 100-year) to evaluate storm conditions. To maintain computational efficiency and allow high model resolution (to capture shoreline features in detail), a small model domain was used. Domain boundary condition input was established using the results of the USACE North Atlantic Coast Comprehensive Study (NAACS), including stillwater elevations and boundary wave heights. A local windfield was applied (for wave generation within the model domain) based on GZA's statistical wind analysis.
3. The tidal condition at the site was developed using NOAA Tides and Currents for the active New London station and subordinate stations at Saybrook Point and Saybrook Jetty and by using NOAA VDATUM. Sea level rise projections were developed using NOAA 2017 and State of Connecticut (CIRCA) guidance.
4. Sill design (i.e., sill geometry and layout) was performed iteratively. The initial design geometry and stone size was developed to achieve the prevailing wave criteria (described above). The starting sill design was then modified based on an evaluation of wave attenuation during different recurrence interval water levels and wave heights.

The evaluation criteria is semi-empirical maximum bottom stresses based on stem breakage and erosion around stem bases. Bottom stresses were developed by GZA based on prediction of orbital velocities associated with the modeled waves. Tidal current velocities at the site are expected to be inconsequential.

5. Mudline elevations for the new marsh were selected based on empirical tide criteria for low marsh growth, with some consideration of sea level rise.
6. The cobble beach was designed to match existing conditions
7. The new dune design was developed based on matching the existing dunes to the east of the project site, which are wider, higher and relatively stable, to provide a continuous dune line. Dune vegetation was selected to match existing.
8. The near-final design was simulated again for the prevailing wave condition and water level/wave conditions for multiple recurrence intervals (up to 100-year) to evaluate storm conditions. Adjustments to the sill layout were made iteratively based on the model results.
9. The dune construction requires relocation of a portion of Crab Creek. Based on stakeholder and client input, a new culvert and re-alignment of a portion of Crab Creek is desirable, pending cost and impact determination. Culvert design would be in conformance with Connecticut DEEP guidance for aquatic stream crossings. Numerical circulation modeling was performed using the 2-dimensional HEC-RAS model to evaluate the existing tidal circulation under normal tidal conditions and extreme flood conditions (2-year, 10-year and 100-year storm scenarios). Model simulations were also performed to evaluate the proposed relocation of Crab Creek and culvert replacement to demonstrate that the proposed modifications will not affect the existing hydraulic conditions within the Lynde Point Marsh and pond or increase the coastal flood hazard of adjacent properties.

RELATIONSHIP WITH CIRCA MISSION AND PRIORITY ISSUES

This project falls directly within CIRCA's broad mission - to increase the resilience and sustainability of vulnerable communities along Connecticut's coast and inland waterways to the growing impacts of climate change on the natural, built, and human environment. Chronic and episodic shoreline erosion have been on-going issues along this small barrier spit. Review of historic photographs and shoreline change data indicates that the shoreline erosion is due, in part, to the construction of coastal structures, including groins and breakwaters, within updrift locations. The Borough has expended significant effort and cost to restore the Lynde Point Marsh and stabilize the beach dune during the last 10 to 15 years; however, shoreline erosion continues. The Borough of Fenwick observed that past restoration methods were unable to sustain the protection provided by the dune and marsh environment. This Living Shoreline Project will be a pilot project to assess effectiveness of living shorelines as a method for shoreline stabilization.

More specifically, this projects meets CIRCA goals:

- ✓ *Improve scientific understanding of the changing climate system and its local and regional impacts on coastal and inland floodplain communities;*
- ✓ *Develop and deploy natural science (living shoreline), engineering (coastal engineering), legal, financial and policy best practices for climate resilience*;
- ✓ *Undertake or oversee pilot projects designed to improve resilience and sustainability of the natural and built environment along Connecticut's coast and inland waterways;*

- ✓ *Create a climate-literate public that understands its vulnerabilities to a changing climate and which uses that knowledge to make scientifically informed, environmentally sound decisions;*
- ✓ *Foster resilient and sustainable communities – particularly along the Connecticut coastline and inland waterways– that can adapt to the impacts and hazards of climate change; and*
- ✓ *Reduce the loss of life and property and natural system and ecological damage from high-impact events.*

Further, the small physical size of the project, the challenging wave environment and the commitment of the project stakeholders toward maintenance of the marsh and beach over the long term makes this project an excellent pilot project.

Green Infrastructure and Living Shorelines is defined as a critical mission element for CIRCA (ref. https://circa.uconn.edu/living-shorelines/). Of particular interest is the performance of the project over time to: 1) effectively stabilize the shoreline, reducing the rate of erosion and risk of breach; 2) survive under, at least higher probability storm events (1 to 10-year recurrence interval; and 3) naturally regrow marsh should it be there be storm-related damage. Specific project areas of interest relative to CIRCA's mission include: 1) use of CIRCA tools; 2) use of CIRCA's reference content; and 3) use of CIRCA-generated data. GZA would be pleased to meet with CIRCA directly to discuss these areas of interest in detail. In general:

1. CIRCA has developed a suitability screening tool that is semi-empirical, but still physics based (https://www.arcgis.com/apps/MapSeries/index.html?appid=150edfcff35d4103afe8a20856067c05). This project has involved similar but more robust analysis. A review the screening criteria at the project vicinity, in comparison to the project findings, may be of interest.
2. CIRCA provides statistical analysis of historic scenario-based wave modeling (https://circa.uconn.edu/crest/). This is useful design input (in particular in conjunction with other observed and synthetic wave data such as NOAA buoys and USACE NAACs) and support a risk-based design approach. This input is limited to storm events (extreme waves). CIRCA may give consideration to enhancing their data set with prevailing wave conditions, which is relatively simple and is essential to Living Shoreline design.
3. CREST Map viewer is a useful tool widely visited by GZA.
4. Connecticut/USGS Shoreline Change Data is a useful tool frequently used by GZA.
5. The suitability screening tool developed by CIRCA would be useful for aligning the Long Island wave climatology and with the Connecticut Living Shoreline criteria in a regulatory framework. For example, the project area screens as suitable for acceptable for offshore breakwaters (not Living Shorelines), which may not be consistent with regulatory goals nor able to be permitted. Also, the CIRCA screening tool supports the conclusion that the project area has a high wave energy environment that typically exceeds the capacity of Living Shorelines and that wave energy attenuation is required.

PROJECT OUTCOMES

Representative project analysis output (Living Shoreline elements only) are presented as follows:

- Project plan is presented in **Appendix A.**
- Photographs documenting the existing conditions are presented in **Appendix B**.
- The Shoreline Change Analysis is presented in **Appendix C**.
- Photographs of Previous Dune Repair and Reinforcement are presented in **Appendix D**.

- GZA's Prevailing Wind and Wave Analysis is presented in **Appendix E**.
- GZA's numerical model results of existing conditions are presented in **Appendix F**.
- GZA's numerical model results of proposed Living Shoreline conditions are presented in **Appendix G**.
- **Appendix H** presents a representative GZA project presentation.
- **Appendix I:** GZA Alternatives Analysis report.
- **Appendix J:** Project Monitoring Plan.

GZA's permitting plan set will be provided to CIRCA under separate cover at a later date.

Lessons Learned

1. Engineering methodology using statistical analysis of wind and waves is a valuable resource for design of Living Shorelines, which have historically been designed almost entirely by "trial and error". This methodology can be implemented on a standardized basis and made efficient using CIRCA-developed tools for design input. See discussion above about CIRCA tools.
2. A risk-based approach should be implemented for design, in particular to align costs with performance expectations. This has not typically been done for coastal engineering projects, including Living Shorelines. As a result, Living Shoreline project failures are likely (if not anticipated by the project owner).
3. Living Shorelines may be perceived as a low cost alternative. The actual costs for construction of this small project are substantial. Larger Living Shoreline projects will readily be in the $millions.
4. The regulatory review and permitting process (even considering use of a Certificate of Permission) is still protracted.
5. Regulatory restrictions, under the current Living Shoreline definition, make use of hybrid structures difficult. This may be a lost opportunity. For example, a stone reinforced dune located outside the tidal zone will provide added storm protection without effecting normal coastal processes. The negative effects (i.e., increased wave reflection and erosion at toe) can clearly be mitigated by constructing a beach and marsh system Living Shoreline, as a hybrid system.
6. Performance monitoring will be a critical information tool.

FINAL PROJECT SCHEDULE AND BUDGET SUMMARY

Development and Evaluation of Living Shoreline Design Alternatives

Scope Item	Schedule
Task 1: Site Inspection and Kick-Off Meeting	Complete
Task 2: Alternatives Analysis	Complete
Task 3: Prepare Comparative Cost Estimates	Complete
Task 4: Prepare Alternatives Analysis Report	Complete
Task 5: Alternative Review Meeting with Borough	Complete
Task 6: Meeting with DEEP, UCONN and Borough Representatives	Complete

100% Engineering Design

<u>Scope Item</u>

Task 7: Nearshore bathymetric and existing wetlands survey	Complete
Task 8: Final Design and Final Report	Complete
Task 9: Project Monitoring Plan	Complete

Permitting

Submitted September, 2019. Expected regulatory review: 6 to 18 months.

Construction

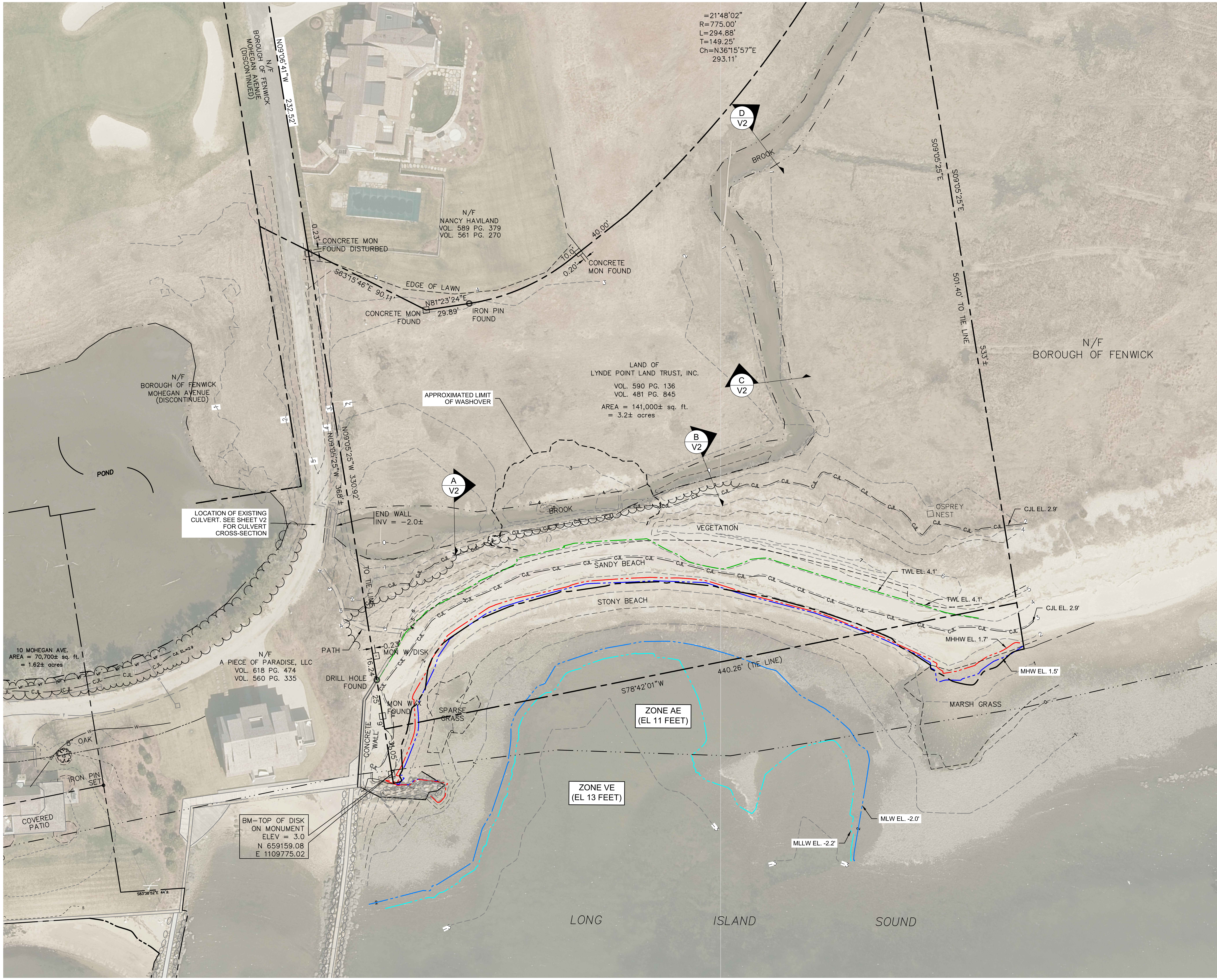
To be determined. Pending regulatory permit review, may be as early as Winter/Spring 2020.

The Borough of Fenwick and GZA will acknowledge in marketing communications with the media or on the Borough of Fenwick's website that the design phase of the Hepburn Dune and Marsh Restoration Living Shoreline Design Project was funded by CIRCA's Municipal Grant program. CIRCA will be acknowledged as a funding partner and invited to participate in presentations and publications about the project.

Construction Budget

The approximate budget for the selected Living Shoreline alternative is: $800k to $900k. The estimated construction cost without the new culvert and Crab Creek realignment (i.e., the Living Shoreline components) is approximately $550k to $700k. Assuming an approximately 500 linear foot project shoreline, this translates to a unit Living Shoreline cost of about $1,100/lf to $1,400/lf.

Appendix A – Project Plan



GENERAL NOTES

1. DATUM: CONTOURS AND POINTS REFERENCE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88). HORIZONTAL DATUM REFERENCES NORTH AMERICAN DATUM OF 1983 (NAD83) CONNECTICUT STATE PLANE COORDINATE SYSTEM, US FOOT.
2. EXISTING CONDITIONS AND PROPERTY CAD FILE PROVIDED BY ANNINO SURVEY INC. TITLED "HEPBURN-PM-EMAIL.DWG" DATED OCTOBER 2008. SEE SHEET G-2 FOR ADDITIONAL NOTES PROVIDED BY SURVEYOR.
3. AN ELECTRONIC ELEVATION AND PROPERTY SURVEY OF 10 MOHEGAN AVE. LOCATED IN THE SOUTHWEST CORNER OF DRAWINGS WAS PREPARED BY ANNINO SURVEY, LLC FOR BARRY M. GOSIN AND JACQUELINE S. GOSIN. GOSIN-DUNE-EX-071018-EMAIL.DWG, TITLED "GENERAL LOCATION SURVEY" DATED JULY 10, 2018, SCALE 1"=20'. SEE SHEET G-2 FOR ADDITIONAL NOTES PROVIDED BY SURVEYOR.
4. ADDITIONAL TOPOGRAPHY AND SURVEY CONTROL LOCATION PERFORMED BY GZA GEOENVIRONMENTAL, INC. ON FEBRUARY 19, 2019 AND MAY 21, 2019. SURVEY CONTROL LOCATIONS USING REAL-TIME KINEMATIC DIFFERENTIAL GLOBAL POSITIONING SYSTEM UNIT (RTK DGPS) USED TO REORIENT THE SURVEY DRAWING PROVIDED BY NLJA TO CONNECTICUT STATE PLANE COORDINATE SYSTEM.
5. AERIAL IMAGE FROM GOOGLE EARTH, DATED OCTOBER 2016. IMAGE SAVED SEPTEMBER 20, 2017.
6. ALL UNDERGROUND UTILITIES SHOWN ON THIS PLAN WERE PROVIDED BY OTHERS AND ARE APPROXIMATE ONLY.

LEGEND

- PROPERTY/STREET LINE
- FLOOD ZONE BOUNDARY FEMA BASE FLOOD ELEVATION (BFE) INDICATED
- EDGE OF STREAM/POND/
- CJL — COASTAL JURISDICTION LINE (CJL)
- WF — WETLAND
- 50-FOOT WETLAND SETBACK
- EXISTING CONTOUR (MAJOR 5 FOOT INTERVAL)
- EXISTING CONTOUR (MINOR 1 FOOT INTERVAL)
- TWL EL. 4.1 — TIDAL WETLAND LIMIT
- MHHW EL. 1.7 — MEAN HIGH HIGH WATER
- MHW EL. 1.5 — MEAN HIGH WATER
- MLW EL. −2.0 — MEAN LOW WATER
- MLLW EL. −2.2 — MEAN LOW LOW WATER
- BRUSH LINE
- D — STORM SEWER/CATCH BASIN
- E — UNDERGROUND ELECTRIC
- T — UNDERGROUND TELEPHONE
- C — UNDERGROUND CABLE TV

NOTE: SEE DRAWING G-2 FOR DRAWING REFERENCE NOTES.

N E S W

PERMITTING ONLY
NOT FOR CONSTRUCTION

0 15' 30' 60' 90'
SCALE IN FEET 1" = 30'

NO.	ISSUE/DESCRIPTION	BY	DATE

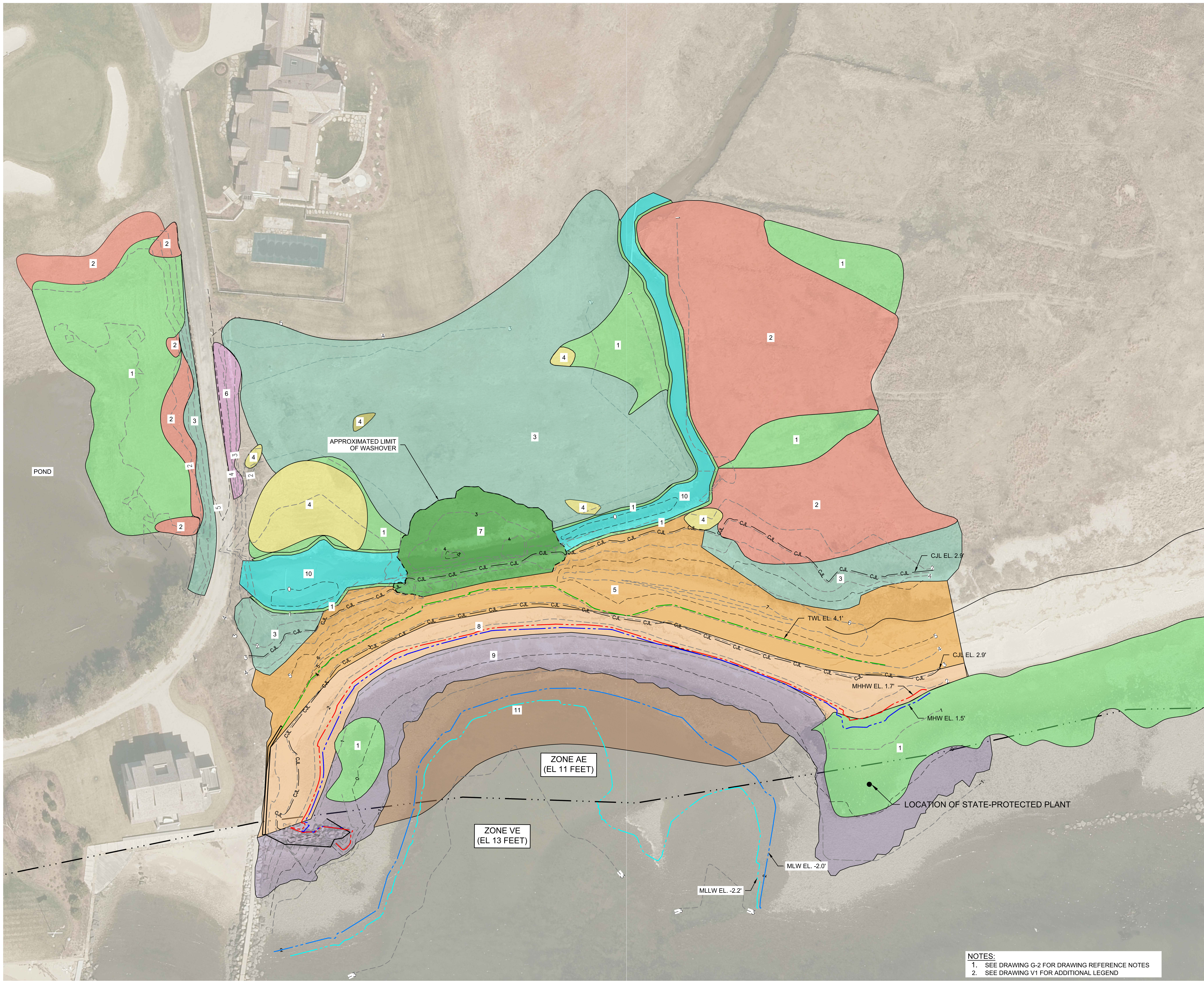
HEPBURN PRESERVE LIVING SHORELINE PROJECT
LYNDE POINT LAND TRUST, INC.
OLD SAYBROOK, CONNECTICUT

EXISTING CONDITIONS PLAN

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: HM	REVIEWED BY: RJM	CHECKED BY: DCS	SHEET
DESIGNED BY: HM	DRAWN BY: LDT	SCALE: AS SHOWN	V1
DATE: AUGUST, 2019	PROJECT NO. 34368.01	REVISION NO. 0	SHEET NO. 2 OF 13



AREA 1: LOW MARSH – 42,200 SF		
Common Name	Botanical Name	Occurrence
Smooth Cordgrass	*Spartina alterniflora*	M
Salt Reed Grass	*Scirpus cynosuriodes*	C
Three-square Sedge	*Scirpus americanus*	F
Cotton Cattail	*Typha latifolia*	F

Occurrence: F=Few <5%, C=Common: 5-25%; M=Many: >25%; I=Invasive Species

AREA 2: HIGH MARSH – 31,040 SF		
Common Name	Botanical Name	Occurrence
Salt Meadow Hay	*Spartina patens*	M
Saltmarsh Bulrush	*Scirpus robustus*	C
Seaside Goldenrod	*Solidago sempervirens*	C
Panic Grass	*Panicum sp.*	F
Narrow-leaf Cattail	*Typha angustifolia*	C
Black Grass	*Juncus gerardi*	F
Salt-marsh Fleabane	*Pluchea odorata*	F
Orach	*Atriplex patula*	F
Tall Cordgrass	*Spartina cynosuroides*	F

Occurrence: F=Few <5%, C=Common: 5-25%; M=Many: >25%; I=Invasive Species

AREA 3: MARITIME SHRUBLAND – 44,750 SF		
Common Name	Botanical Name	Occurrence
Marsh Elder	*Iva frutescens*	M
Seaside Goldenrod	*Solidago sempervirens*	F
Switch Grass	*Panicum virgatum*	M
Umbrella Flatsedge	*Cyperus diandrus*	F
Wild Rye	*Elymus virginicus*	F

Occurrence: F=Few <5%, C=Common: 5-25%; M=Many: >25%; I=Invasive Species

AREA 4: PHRAGMITES - 4,505 SF		
Common Name	Botanical Name	Occurrence
Seaside Goldenrod	*Solidago sempervirens*	C
Phragmites	*Phragmites australis*	M, I
Orach	*Atriplex patula*	F

Occurrence: F=Few <5%, C=Common: 5-25%; M=Many: >25%; I=Invasive Species

AREA 5: DUNE - 20,970 SF		
Common Name	Botanical Name	Occurrence
Seaside Goldenrod	*Solidago sempervirens*	C
Mugwort	*Artemisia vulgaris*	C, I
Common Milkweed	*Asclepias syriaca*	F
Common Yarrow	*Achillea millefolium*	F
American Beach Grass	*Ammophila breviligulata*	M
Queen Anne's Lace	*Daucus carota*	F
Curly Dock	*Rumex crispus*	F
Evening Primrose	*Oenothera biennis*	F, I
Yellow Nutsedge	*Cyperus stigosus*	C, I
Wild Carrot	*Daucus carota*	C

Occurrence: F=Few <5%, C=Common: 5-25%; M=Many: >25%; I=Invasive Species

AREA 6: HONEYSUCKLE - 1,210 SF		
Common Name	Botanical Name	Occurrence
Tartarian Honeysuckle	*Lonicera Tartarian*	M, I
Marsh Edldr	*Ive Frutescens*	C
Raspberry	*Rubus Pubescens*	C

Occurrence: F=Few <5%, C=Common: 5-25%; M=Many: >25%; I=Invasive Species

AREA 7: WASHOVER - 5,920 SF

AREA 8: SANDY BEACH - 11,460 SF

AREA 9: STONY BEACH - 17,060 SF

AREA 10: CRAB CREEK - 7,150 SF

AREA 11: INTERTIDAL NON-VEGETATED - 13,510 SF

NOTES:

1. SEE DRAWING G-2 FOR DRAWING REFERENCE NOTES
2. SEE DRAWING V1 FOR ADDITIONAL LEGEND

NO.	ISSUE/DESCRIPTION	BY	DATE

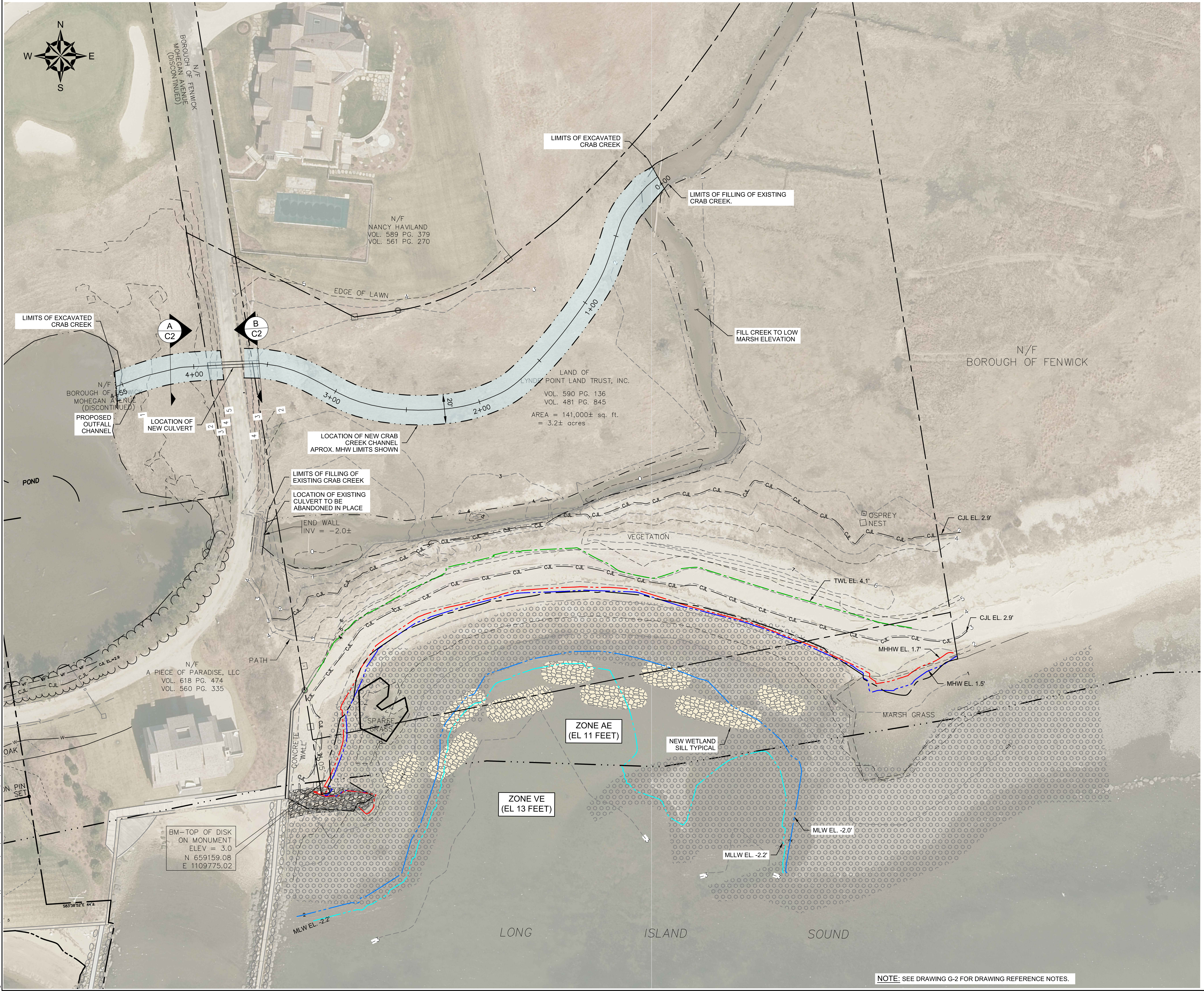
HEPBURN PRESERVE LIVING SHORELINE PROJECT
LYNDE POINT LAND TRUST, INC.
OLD SAYBROOK, CONNECTICUT

EXISTING VEGETATION PLAN

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: HM	REVIEWED BY: RJM	CHECKED BY: DCS	SHEET
DESIGNED BY: HM	DRAWN BY: LDT	SCALE: AS SHOWN	V3
DATE: AUGUST, 2019	PROJECT NO. 34368.01	REVISION NO. 0	SHEET NO. 3 OF 13



NOTE: SEE DRAWING G-2 FOR DRAWING REFERENCE NOTES.

LEGEND

- PROPERTY/STREET LINE
- FLOOD ZONE BOUNDARY FEMA BASE FLOOD ELEVATION (BFE) INDICATED
- EDGE OF STREAM/POND/
- CJL — COASTAL JURISDICTION LINE (CJL)
- WF — WETLAND
- 50-FOOT WETLAND SETBACK
- EXISTING CONTOUR (MAJOR 5 FOOT INTERVAL)
- EXISTING CONTOUR (MINOR 1 FOOT INTERVAL)
- TWL EL. 4.1 — TIDAL WETLAND LIMIT
- MHHW EL. 1.7 — MEAN HIGH HIGH WATER
- MHW EL. 1.5 — MEAN HIGH WATER
- MLW EL. -2.0 — MEAN LOW WATER
- MLLW EL. -2.2 — MEAN LOW LOW WATER
- BRUSH LINE
- D — STORM SEWER/CATCH BASIN
- E — UNDERGROUND ELECTRIC
- T — UNDERGROUND TELEPHONE
- C — UNDERGROUND CABLE TV
- EXISTING BREAKWATER
- APPROXIMATE EXTENT OF EXISTING COBBLES
- EXISTING SALT MARSH IN LIS

PERMITTING ONLY
NOT FOR CONSTRUCTION

0 15' 30' 60' 90'
SCALE IN FEET 1" = 30'

NO.	ISSUE/DESCRIPTION	BY	DATE

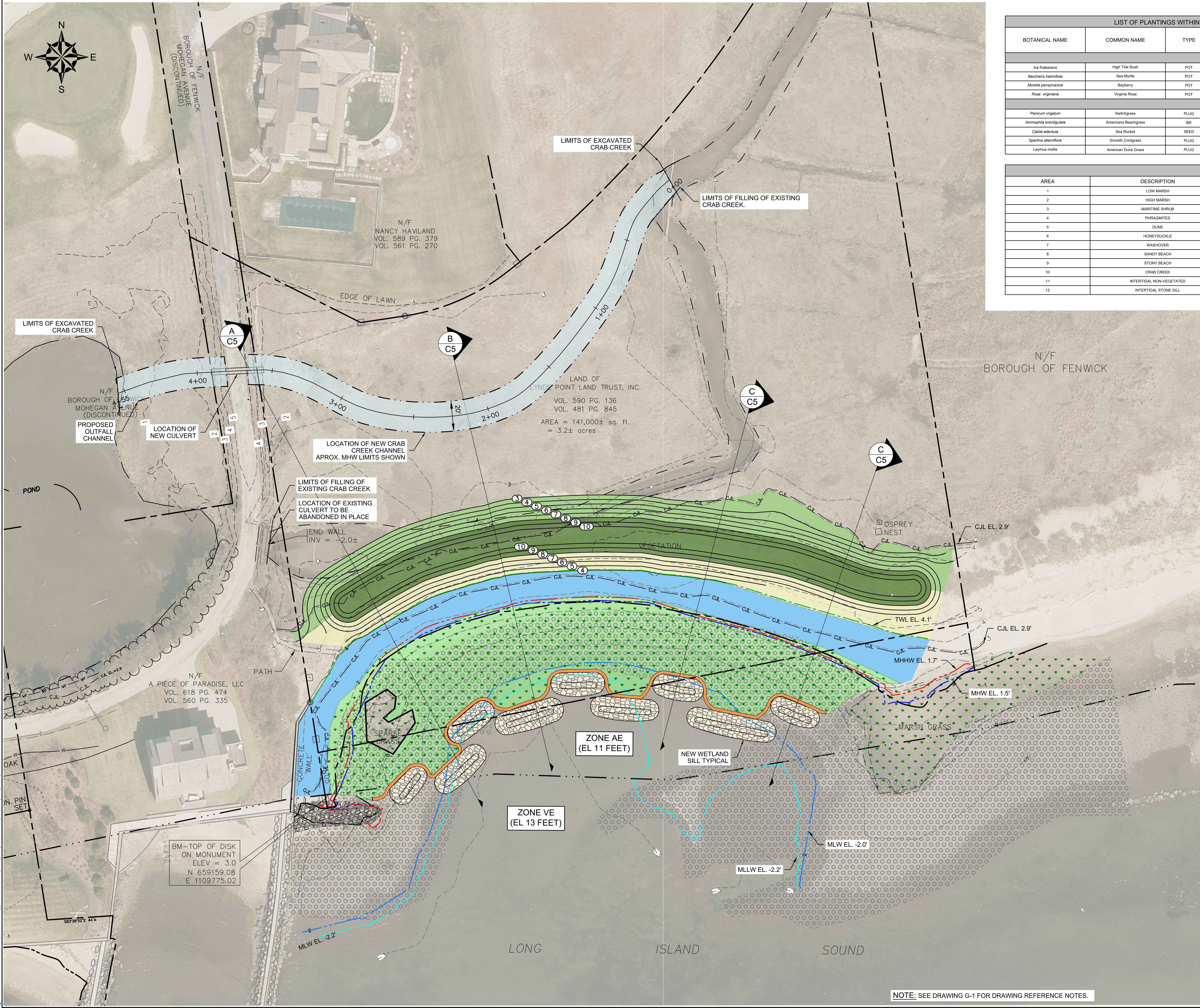
HEPBURN PRESERVE LIVING SHORELINE PROJECT
LYNDE POINT LAND TRUST, INC.
OLD SAYBROOK, CONNECTICUT

RELOCATION OF CRAB CREEK AND NEW CULVERT PLAN

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: JB	REVIEWED BY: MA	CHECKED BY: JB	SHEET
DESIGNED BY: JB	DRAWN BY: GRB/LDT	SCALE: AS SHOWN	C-1
DATE: AUGUST, 2019	PROJECT NO. 34368.01	REVISION NO. 0	SHEET NO. 5 OF 13



LIST OF PLANTINGS WITHIN DUNE RESTORATION BY RESOURCE AREA AND ELEVATION								
BOTANICAL NAME	COMMON NAME	TYPE	SIZE	FORE DUNE	TOP DUNE	BACK DUNE	LOW MARSH	MARITIME SHRUBLAND
				EL. 4.0-8.0	EL. 8.0-11.0	EL. 2.0-8.0	EL. 0.0-2.0	EL. 1.0-2.0
SHRUBS								
Iva frutescens	High Tide Bush	POT	2-4'					X
Baccharis halimifolia	Sea Myrtle	POT	2-4'					X
Morella pensylvanica	Bayberry	POT	2-4'			X		
Rosa virginiana	Virginia Rose	POT	2-4'		X	X		
GRASSES AND FORBS								
Panicum virgatum	Switchgrass	PLUG	2"			X		
Ammophila breviligulata	Americana Beachgrass	BR	6"	X	X	X		
Cakile edentula	Sea Rocket	SEED	lbs.			X		
Spartina alterniflora	Smooth Cordgrass	PLUG	6"				X	
Leymus mollis	American Dune Grass	PLUG	6"		X			

HABITAT AREAS CHANGES				
AREA	DESCRIPTION	EXISTING (SF)	PROPOSED (SF)	NET CHANGE (SF)
1	LOW MARSH	42,200	60,040	17,840
2	HIGH MARSH	31,040	38,320	7,280
3	MARITIME SHRUB	44,750	30,100	-14,650
4	PHRAGMITES	4,505	0	-4,505
5	DUNE	20,970	26,070	5,100
6	HONEYSUCKLE	1,210	970	-240
7	WASHOVER	5,920	0	-5,920
8	SANDY BEACH	11,460	1,150	-10,310
9	STONY BEACH	17,060	10,310	-6,750
10	CRAB CREEK	7,150	6,820	-330
11	INTERTIDAL NON-VEGETATED	13,510	0	-13,510
12	INTERTIDAL STONE SILL	0	5,140	5,140

LEGEND

- PROPERTY/STREET LINE
- FLOOD ZONE BOUNDARY FEMA BASE FLOOD ELEVATION (BFE) INDICATED
- EDGE OF STREAM/POND/
- CJL — COASTAL JURISDICTION LINE (CJL)
- WF — WETLAND
- 50-FOOT WETLAND SETBACK
- EXISTING CONTOUR (MAJOR 5 FOOT INTERVAL)
- EXISTING CONTOUR (MINOR 1 FOOT INTERVAL)
- TWL EL. 4.1 — TIDAL WETLAND LIMIT
- MHHW EL. 1.7 — MEAN HIGH HIGH WATER
- MHW EL. 1.5 — MEAN HIGH WATER
- MLW EL. −2.0 — MEAN LOW WATER
- MLLW EL. −2.2 — MEAN LOW LOW WATER
- BRUSH LINE
- D — STORM SEWER/CATCH BASIN
- E — UNDERGROUND ELECTRIC
- T — UNDERGROUND TELEPHONE
- C — UNDERGROUND CABLE TV
- EXISTING BREAKWATER
- APPROXIMATE EXTENT OF EXISTING COBBLES
- EXISTING SALT MARSH IN LIS
- PROPOSED STONE SILL
- COIR LOG MARSH EDGE
- REDISTRIBUTED COBBLE BEACH
- PROPOSED SAND PLACEMENT & SALT MARSH PLANTINGS

PERMITTING ONLY
NOT FOR CONSTRUCTION

0 15' 30' 60' 90'
SCALE IN FEET 1" = 30'

NO.	ISSUE/DESCRIPTION	BY	DATE

HEPBURN PRESERVE LIVING SHORELINE PROJECT
LYNDE POINT LAND TRUST, INC.
OLD SAYBROOK, CONNECTICUT

LIVING SHORELINE PROPOSED CONDITIONS

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

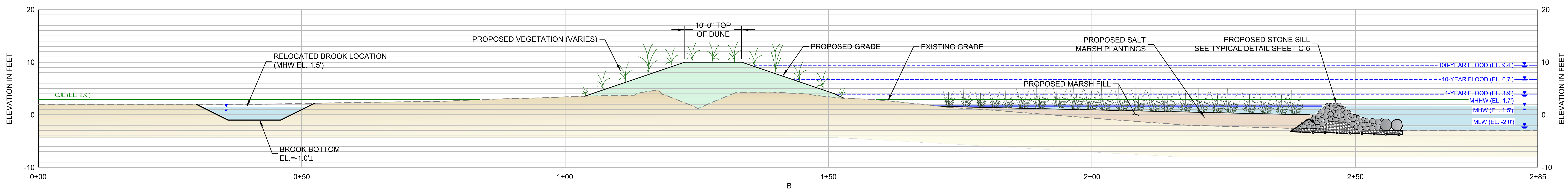
PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: JB	REVIEWED BY: MA	CHECKED BY: JB	SHEET
DESIGNED BY: JB	DRAWN BY: GRB/LDT	SCALE: AS SHOWN	C-4
DATE: AUGUST, 2019	PROJECT NO. 34368.01	REVISION NO. 0	SHEET NO. 8 OF 13

NOTE: SEE DRAWING G-1 FOR DRAWING REFERENCE NOTES.

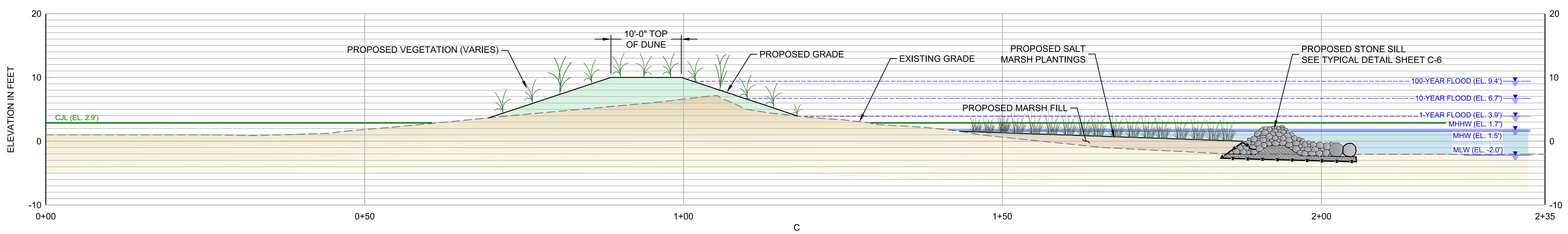
CROSS SECTION (SECTION A)

SCALE: 1"=10'



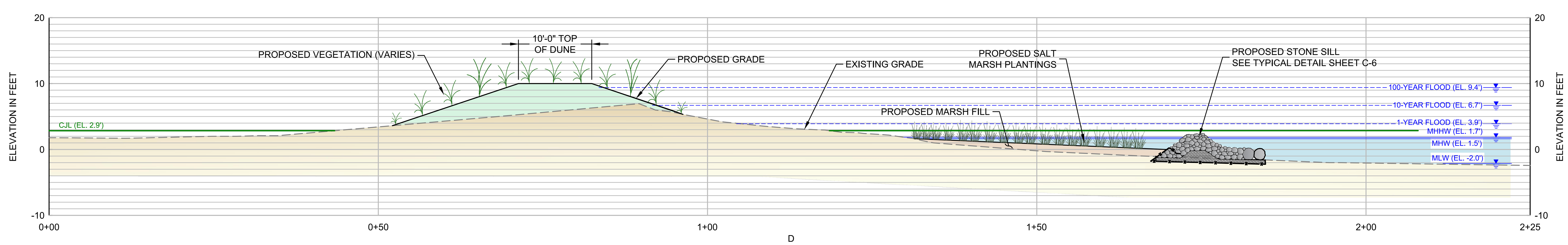
CROSS SECTION (SECTION B)

SCALE: 1"=10'



CROSS SECTION (SECTION C)

SCALE: 1"=10'



CROSS SECTION (SECTION D)

SCALE: 1"=10'

NOTES:

1. SEE DRAWING G-2 FOR DRAWING REFERENCE NOTES
2. WATER LEVELS SHOWN ARE "STILLWATER ELEVATIONS" AND DO NOT INCLUDE WAVE EFFECTS (WAVE SET-UP AND / OR RUN UP).

PERMITTING ONLY
NOT FOR CONSTRUCTION

0 5' 10' 20' 30'
SCALE IN FEET 1" = 10'

NO.	ISSUE/DESCRIPTION	BY	DATE

HEPBURN PRESERVE LIVING SHORELINE PROJECT
LYNDE POINT LAND TRUST, INC.
OLD SAYBROOK, CONNECTICUT

LIVING SHORELINE CROSS-SECTIONS

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: HM	REVIEWED BY: RJM	CHECKED BY: DCS	SHEET
DESIGNED BY: HM	DRAWN BY: CRB	SCALE: AS SHOWN	C-5
DATE: AUGUST, 2019	PROJECT NO. 34368.01	REVISION NO. 0	SHEET NO. 9 OF 13

Appendix B – Photos of Existing Conditions

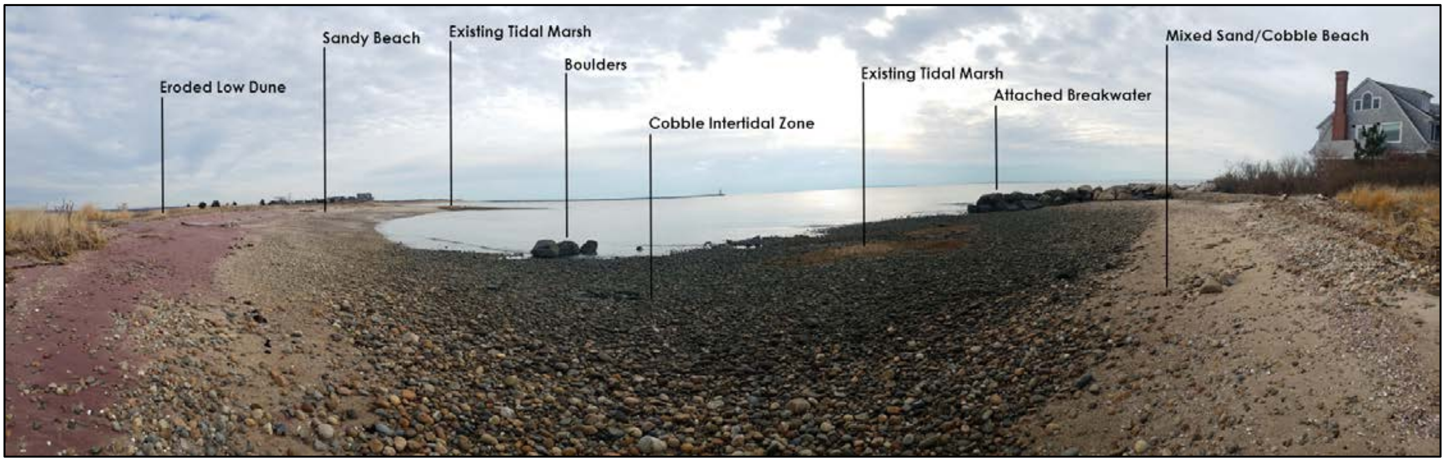


Figure 1 Existing shoreline conditions pre-2019 dune breach (looking south at low tide)

Figure 2 Existing shoreline conditions (looking south at high tide)

Figure 3 Existing dune and marsh conditions pre-2019 dune breach (looking west at mid tide)

Figure 4 Existing shoreline conditions at west end of site (looking northeast at low tide)

Figure 5 Existing attached breakwater at west end of site (looking northeast at mid-tide)

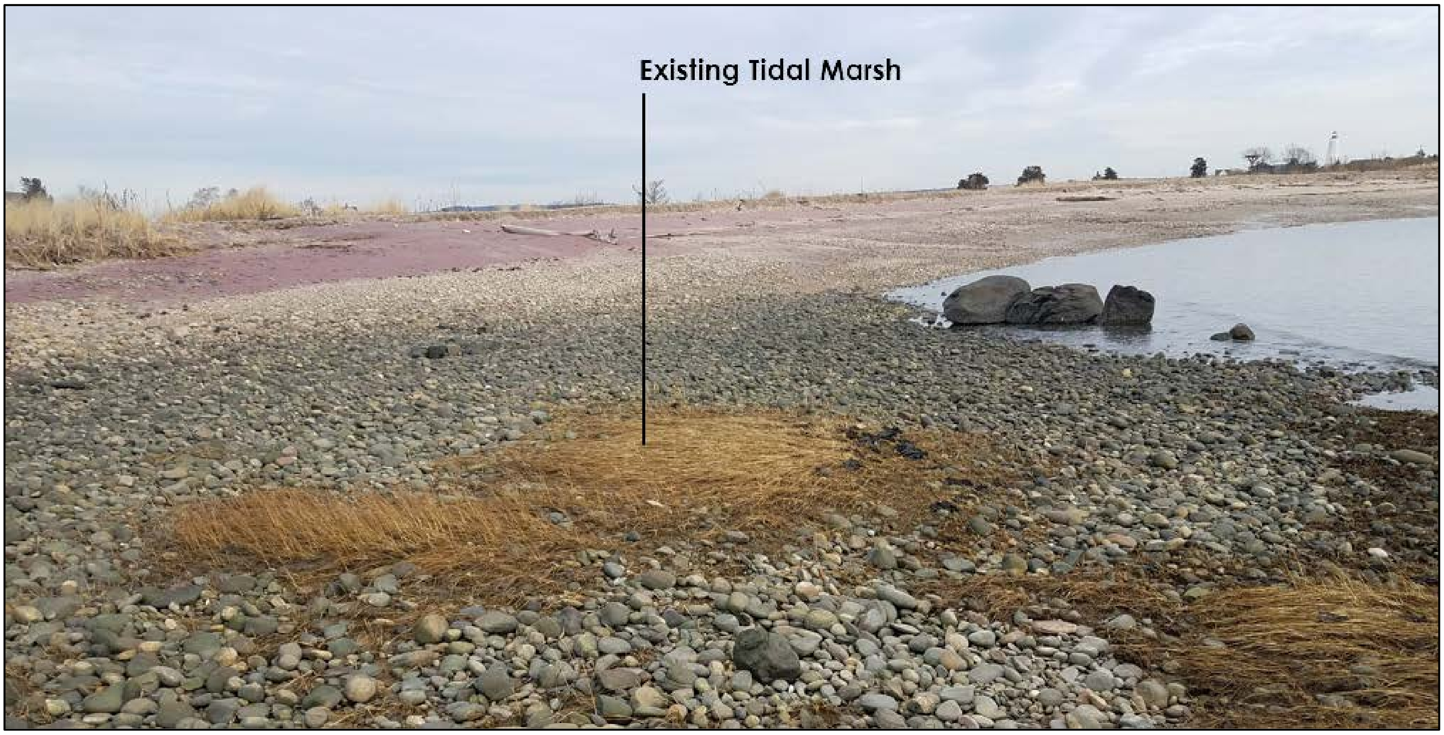


Figure 6 Existing tidal marsh among cobble intertidal zone at west end of site (looking northeast at low tide)

Figure 7 Natural or manmade line of boulders, acting as a sill, contributing to existing marsh growth

Figure 8 Existing Hepburn Dune pre-2019 dune breach (looking west at low tide)

Figure 9 Cobble/Sand composition of existing Hepburn Dune shown after storm-induced erosion (looking north, pre-2019 dune breach)

Figure 10 Existing tidal marsh, cobble intertidal zone at east end of site (looking north at low tide)

Figure 11 Existing tidal marsh, cobble intertidal zone and sandy beach at east end of site (looking west at low tide)

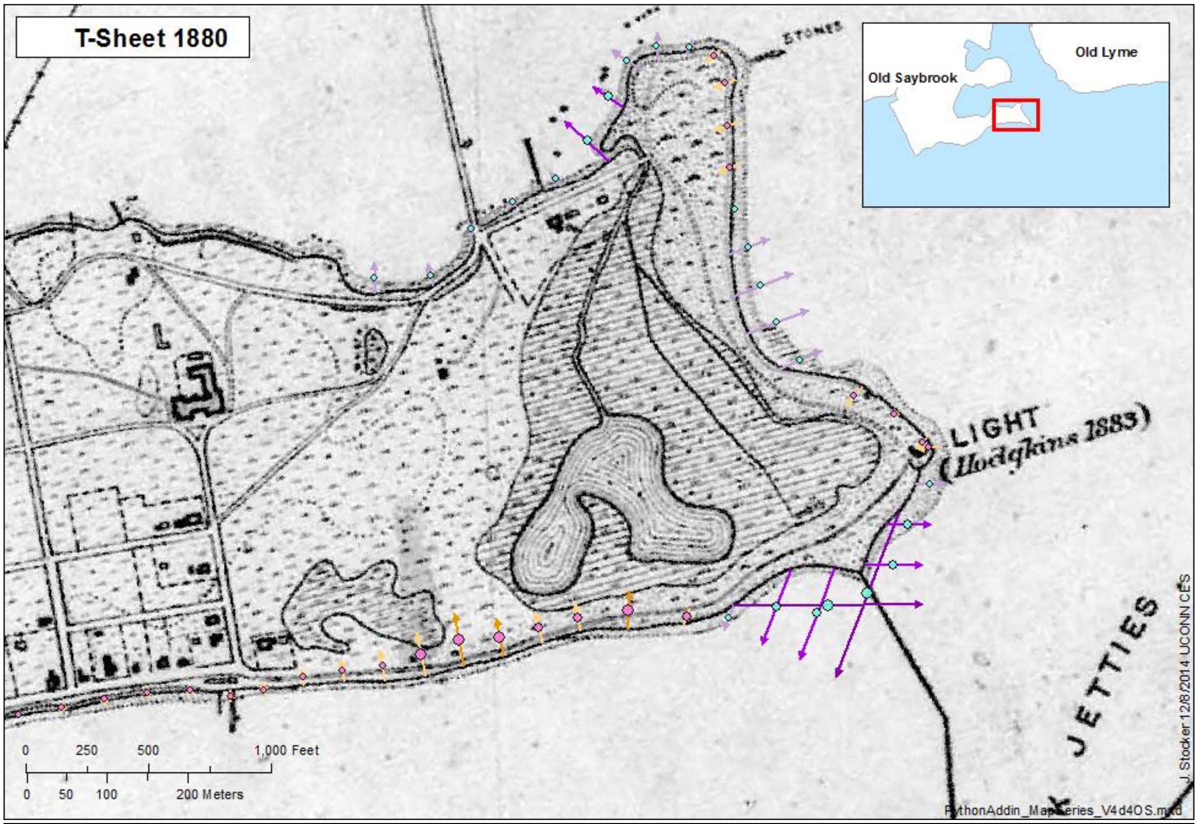
Figure 12 Storm-induced dune breach and infilling of Crab Creek with overwash material looking East (Winter 2019)

Figure 13 Storm-induced dune breach and infilling of Crab Creek with overwash material looking West (Winter 2019)

Figure 14 2019 Winter Storm Emergency Response Project: Corrugated pipe (western end of the pipe) to restore tidal connectivity and dune restoration

Figure 15 2019 Winter Storm Emergency Response Project: Corrugated pipe (eastern end of the pipe) during ebb flow conditions

Appendix C – Shoreline Change Analysis


T-Sheet 1880
Old Saybrook
Old Lyme
STONES
LIGHT
(Hodgkins 1883)
JETTIES
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


March 1934
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
CT State Library for the scanned aerial photographs. The University of Connecticut Library MAGIC program for the online access to scanned historic images. The Univerisity of Connecitcut Cooperative Extension System for rectifying the images.
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


March 1957
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


March 1965
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


March 1990
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
PythonAddin_MapSeries_V4d4OS.mxd


March 2004
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


June 2005
Old Saybrook
Old Lyme


June 2006
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


June 2008
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


June 2010
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


June 2012
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


November 2012
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd

LEGEND

Short Term Net Shoreline Movement (NSM)

End Point Rate m/yr (1983-2006)

- 0.00 - 0.31
- 0.32 - 1.01
- 1.02 - 2.20
- 2.24 - 3.97
- 4.25 - 6.11

Short Term Net Shoreline Movement (NSM)

End Point Rate m/yr (1983-2006)

- -5.16 - -1.50
- -1.49 - -0.71
- -0.70 - -0.35
- -0.34 - -0.13
- -0.12 - 0.00

Service Layer Credits: Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS

HEPBURN DUNE AND MARSH PRESERVATION LIVING SHORELINE PROJECT

OLD SAYBROOK, CONNECTICUT

SHORT TERM NET SHORELINE MOVEMENT

PREPARED BY: GZA GeoEnvironmental, Inc. Engineers and Scientists www.gza.com

PREPARED FOR: Town of Old Saybrook

PROJ MGR: PM	REVIEWED BY: REV	CHECKED BY: CKD	FIGURE
DESIGNED BY: DES	DRAWN BY: DRN	SCALE: 1" = 200 FEET	1
DATE: 02/28/2018	PROJECT NO. 03.0034368.00	REVISION NO.	SHEET NO.

LEGEND

Long Term Net Shoreline Movement (NSM)

End Point Rate m/yr (1880s-2006)

- 0.00 - 0.31
- 0.32 - 1.01
- 1.03 - 2.20
- 2.34 - 3.97
- 4.34 - 6.11

Long Term Net Shoreline Movement (NSM)

End Point Rate m/yr (1880s-2006)

- -5.16 - -1.5
- -1.44 - -0.71
- -0.70 - -0.35
- -0.34 - -0.13
- -0.12 - 0.00

HEPBURN DUNE AND MARSH PRESERVATION
LIVING SHORELINE PROJECT
OLD SAYBROOK, CONNECTICUT

LONG TERM NET SHORELINE MOVEMENT

PREPARED BY: GZA GeoEnvironmental, Inc. Engineers and Scientists www.gza.com		PREPARED FOR: Town of Old Saybrook	
PROJ MGR: PM	REVIEWED BY: REV	CHECKED BY: CKD	FIGURE
DESIGNED BY: DES	DRAWN BY: DRN	SCALE: 1 " = 200 FEET	2
DATE: 02/28/2018	PROJECT NO. 03.0034368.00	REVISION NO.	SHEET NO.

Appendix D – Photographs of Previous Dune Repair & Reinforcement

Hepburn Dune Restoration Project 2007: Filtrex tubing filled with sand and mulch

Hepburn Dune Restoration Project 2007: Filtrex tubing filled with sand and mulch

Hepburn Dune Restoration Project Fall 2007: Filtrexx tubing covered with sand

Hepburn Dune Restoration Project March 2008: Dunes planted with American beach grass and Switchgrass

Hepburn Dune Restoration Project: Plantings become well established

Hurricane Irene (shown) in 2011 and Superstorm Sandy in 2012 caused extensive damage to the dune restoration project

Following Superstorm Sandy, the dune had been leveled, the Filtrexs tubing was lost, and overwash sediment was deposited in the marsh

Appendix E – Wind and Wave Analysis

WIND CLIMATE ANALYSIS

To analyze the local wind patterns (which ultimately drive wave patterns and sediment transport), GZA conducted a statistical analysis of historical wind data (1943-2017) from the Groton-New London Airport located approximately 16 miles to the east. The complete data set is plotted below as a wind rose which shows wind frequency and magnitude throughout the historical record coming from 32 different directional bins (Figure 1). These data show that predominant wind directions here are from the southwest and northwest. When these wind data were further split into four seasons, typical seasonality of winds on the Connecticut coast were identified including winds predominantly from the southwest in the Summer and from the northwest in the Winter with transition periods in the Spring and Fall.

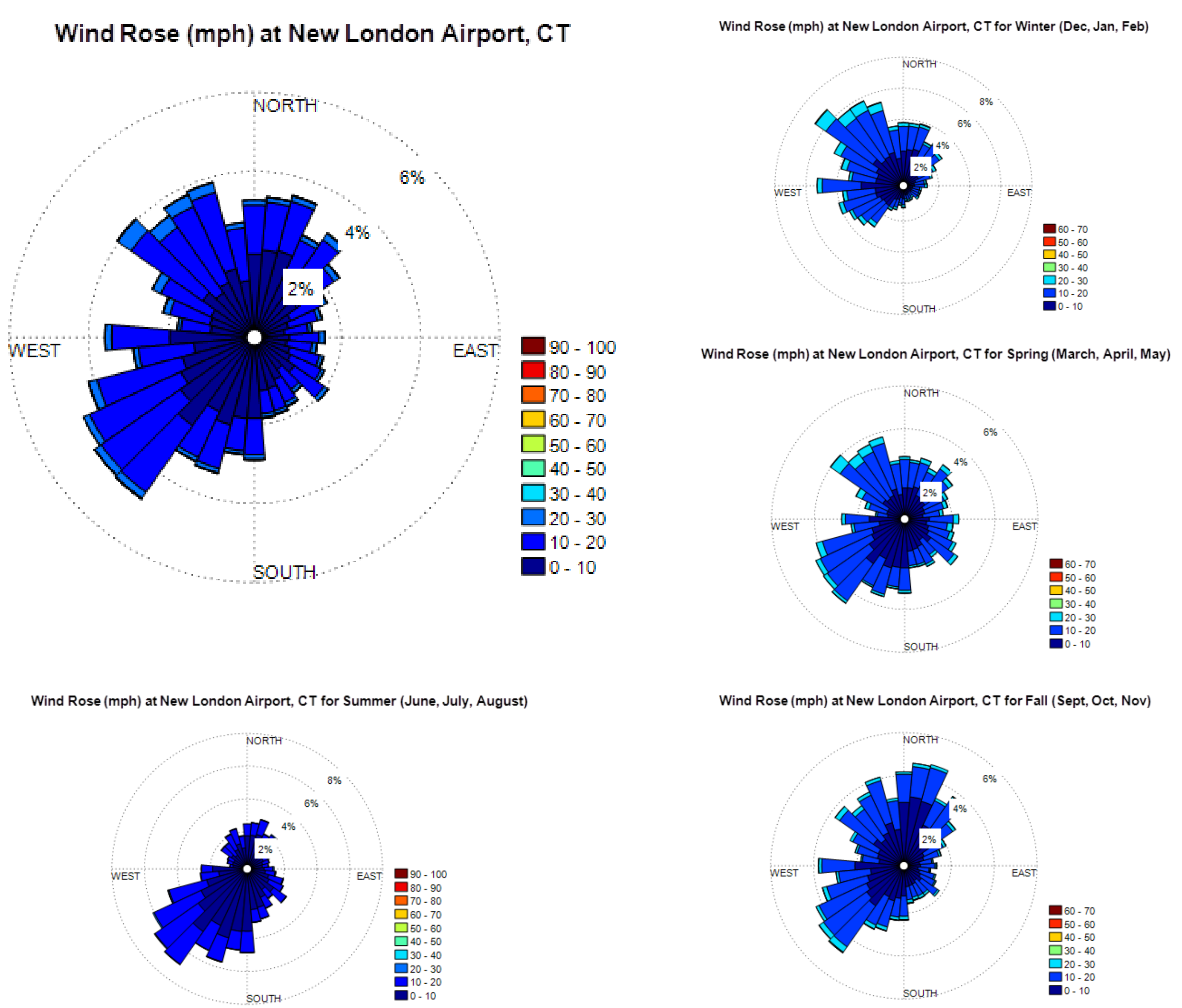


Figure 1. Wind Rose (10 m height, 1-minute sustained wind speed in mph, New London, CT) showing magnitude, direction, and percent frequency of winds from 1943-2017 (top left) and split into four seasons

To determine the direction from which the strongest winds impact the site (and therefore the biggest storms), these data were then divided into six categories of magnitude from winds 0-10 mph to winds greater than 50 mph, and a wind rose was plotted for each category (Figure 2). This analysis shows that the strongest winds impacting the site (> 50 mph) are from the due south.

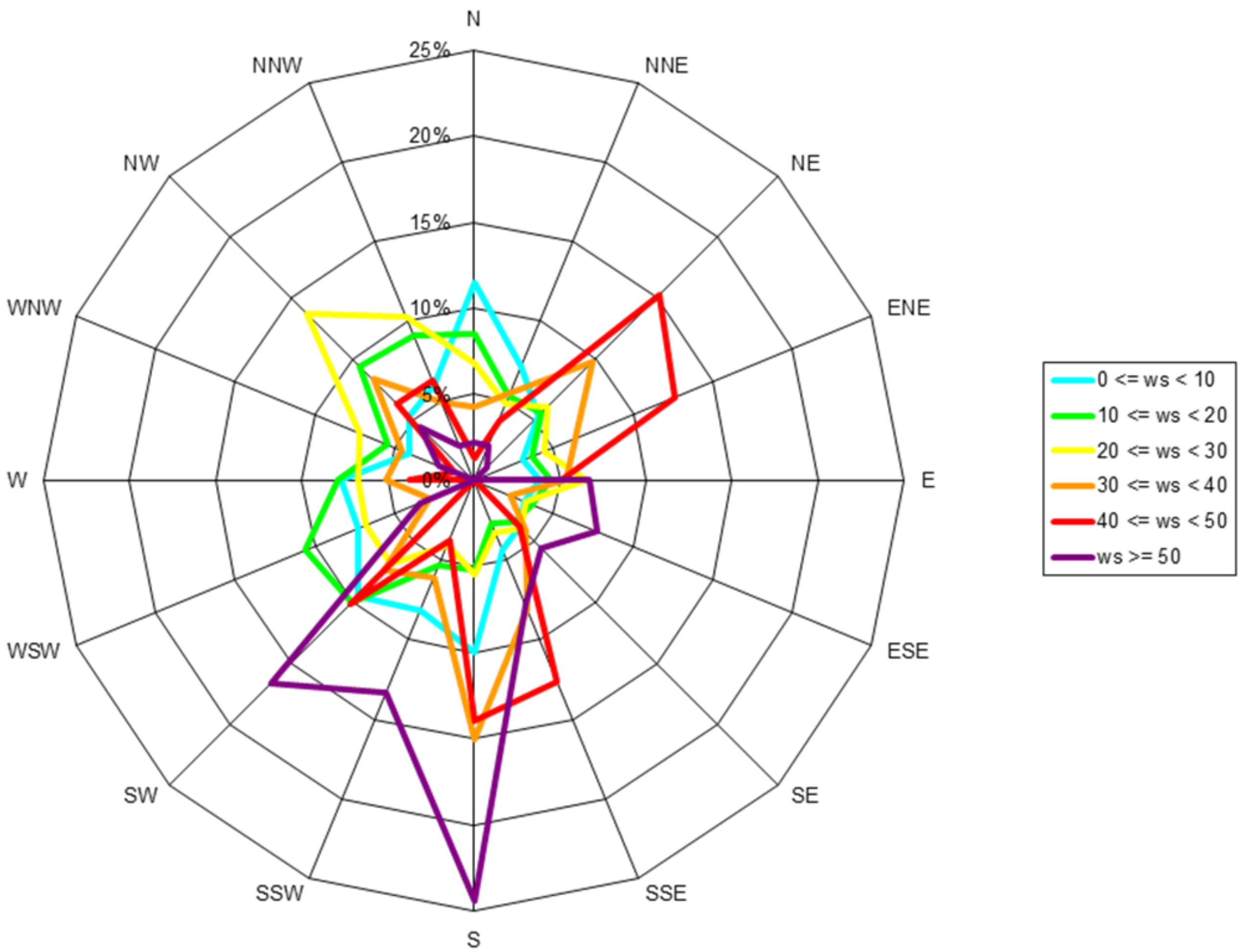


Figure 2. Wind Rose indicating frequency and direction of winds divided into six bins of magnitude from 0-10mph to >50mph (10 m height, 1-minute sustained wind speed in mph, New London, CT)

WAVE CLIMATE ANALYSIS

Wave climate is defined as the distribution of wave parameters (wave height, wave period and wave direction) averaged over a defined time interval at a particular location. Understanding a project site's wave climate is important in designing a successful shore protection strategy. It is useful to understand both low probability higher waves that are associated with storm wave conditions driving short-term shoreline change as well as higher probability lower waves associated with prevailing wave conditions driving long-term shoreline change. For instance, green coastal protection measures such as marshes and sills are often inundated during storm events because of surge. Higher water elevations allow waves to surpass the living shoreline features making wave energy less of a performance concern for their design. For these features, most erosion is observed with the long-term impacts of high probability lower wave heights and thus, these conditions represent the most critical condition for designing living shoreline elements. For design features such as dunes

in which the goal is to prevent a breach, lower probability storm wave conditions that could lead to a breach over a short time period become a more critical design condition.

Since wave climatology data does not exist for this project site and wave climate is driven by local wind patterns, GZA used historical wind data (1943-2017) from the Groton-New London Airport to recreate a historical wave record. This process is known as “hindcasting” and entails calculating wave heights and directions using standard formulas from the USACE Shore Protection Manual (1984) based on known wind speed and direction data, fetch distance and average water depth. For this project, hindcasting of wave data was conducted for seven directional bins (each 22.5 degrees) from which waves impact the project site (Figure 3).

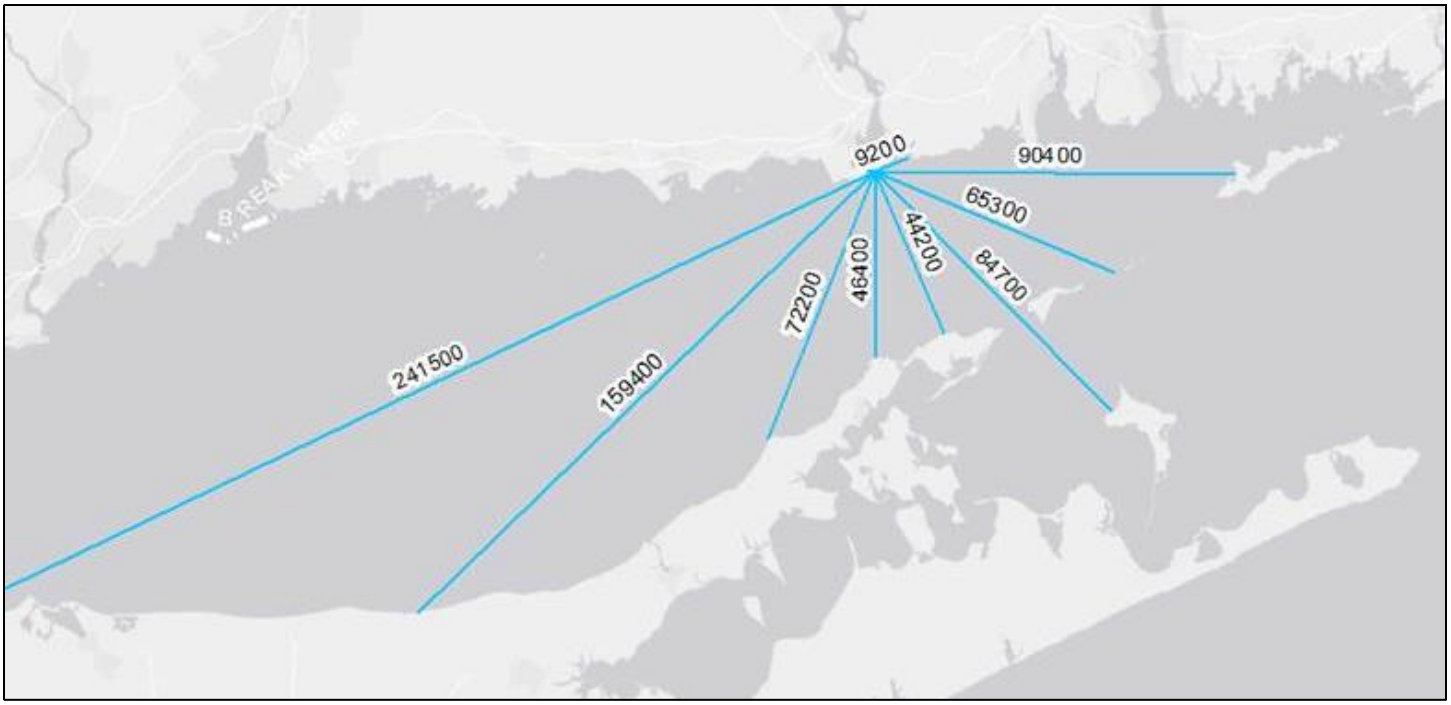


Figure 3. Directional bins and distances (feet) for which wave hindcast statistics were calculated at the project site

Figure 4 illustrates a statistical analysis of wave frequency based on hindcasting data described above within each directional bin. This analysis reveals that for the hindcast data calculated for the site, waves from the west-southwest (shown in light blue) exhibit a higher wave height with more frequency than from other directions. Therefore, waves from the west-southwest are likely the main drivers of shoreline change at the site under predominant conditions.

This statistical analysis of wave frequency is also useful in determining the need for attenuating wave energy at the site with structural elements in order to assure saltmarsh survivability if that is a planned restoration component of a living shoreline project. Research conducted by Shafer (Shafer et. Al, 2003) identifies a threshold wave height for marsh survivability and successful growth. This study estimated through field research that saltmarshes can survive in wave climates in which wave heights exceed 0.14m (0.46ft) no more than 20 percent of the time. This value is also known as the 20-percent exceedance wave height ($H_{20\%}$). For the Hepburn Dune project site (based on statistical analysis of the hindcast wave data described above), the $H_{20\%}$ is 0.27m (0.89ft) as shown in Figure 5. Because the $H_{20\%}$ calculated for this site exceeds 0.14m, the use of wave attenuation structures such as sills or breakwaters will be required to reduce the wave energy environment if saltmarsh restoration is a desired component of the living shoreline design.

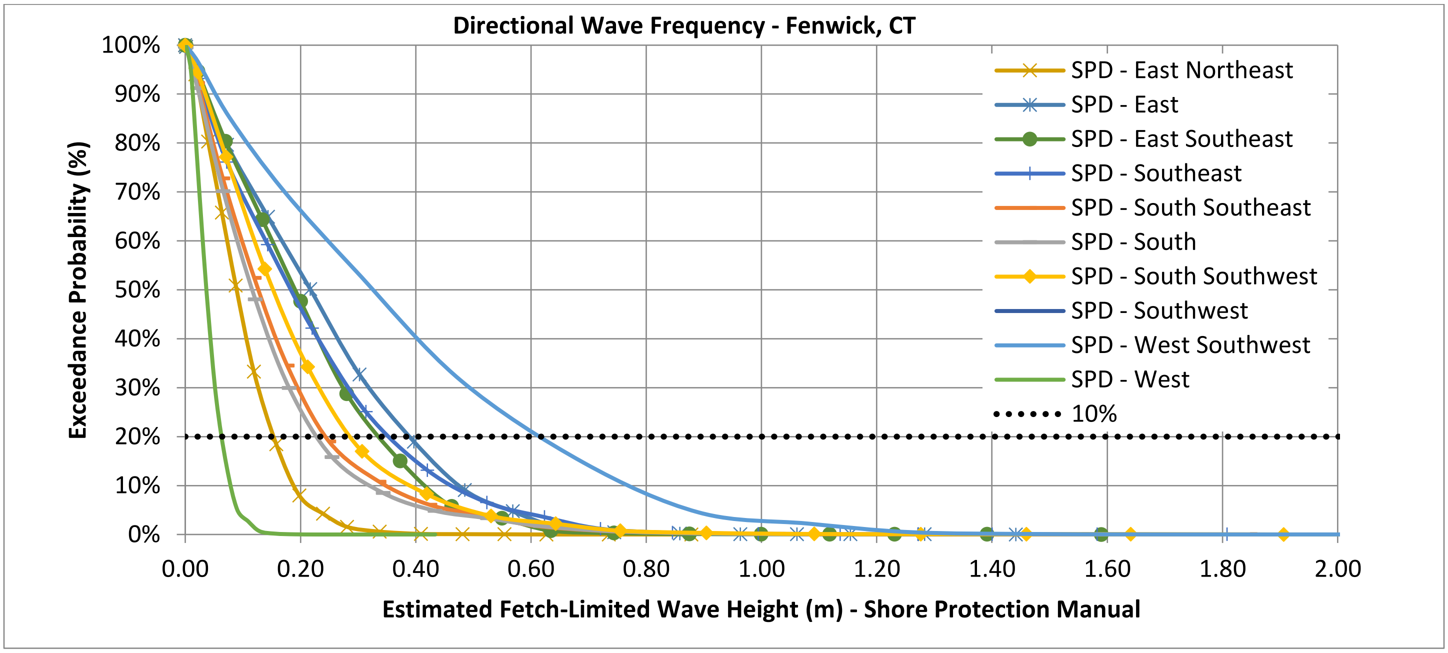


Figure 4. Directional wave frequency statistics and 20% exceedance wave height for each directional bin

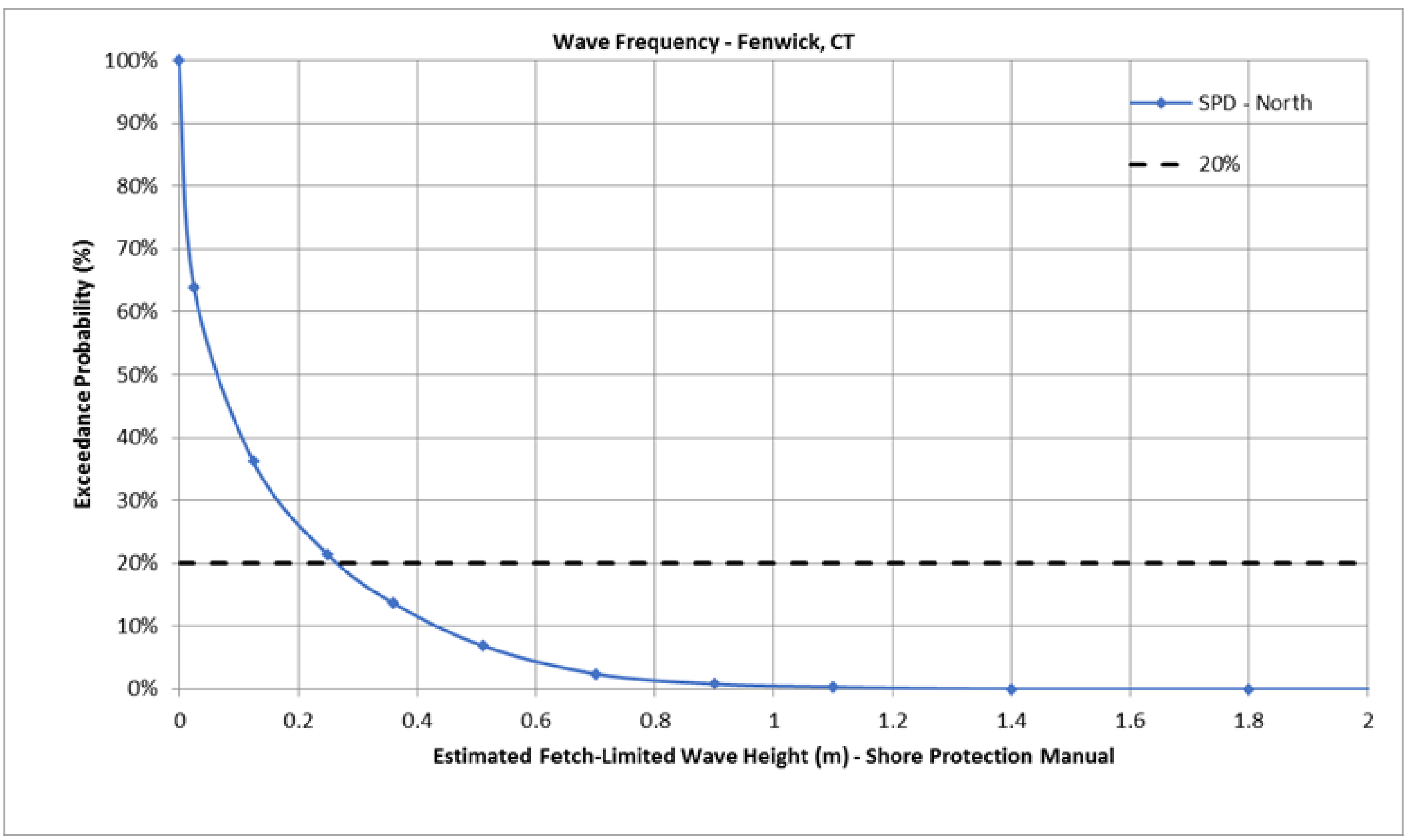
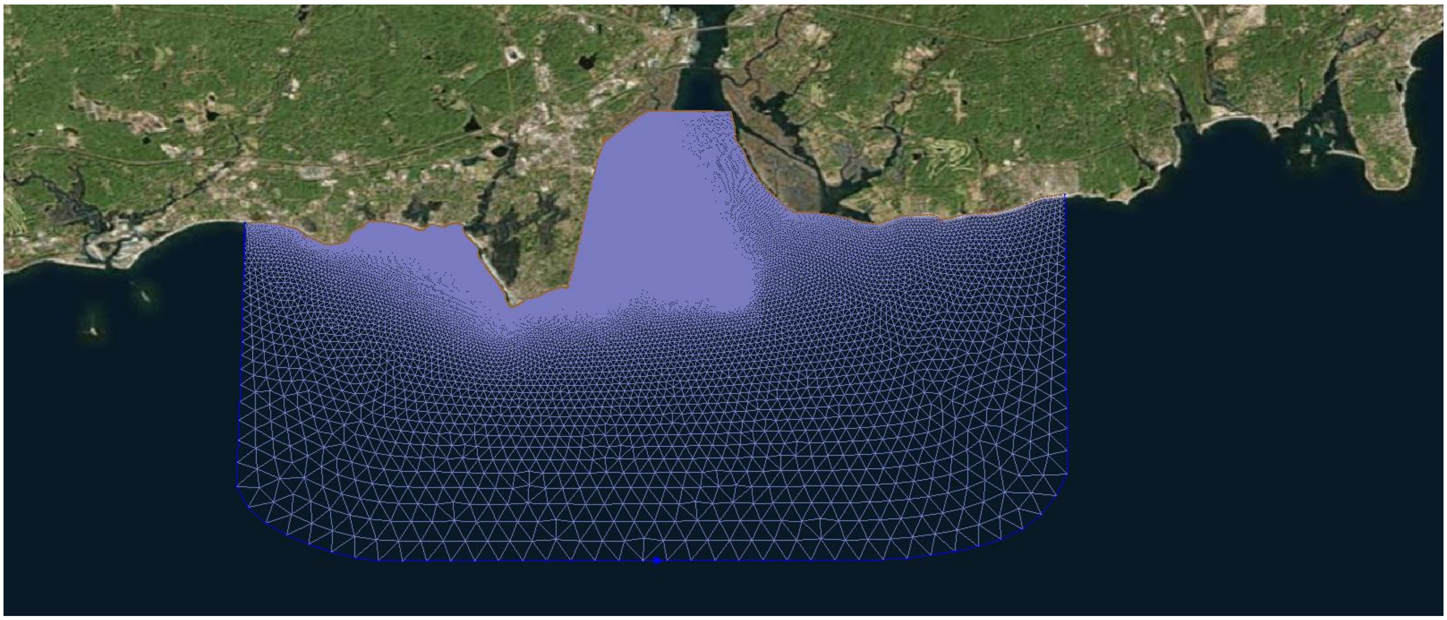


Figure 5. Wave frequency statistics for entire wave data set and 20% exceedance wave height (0.27m)

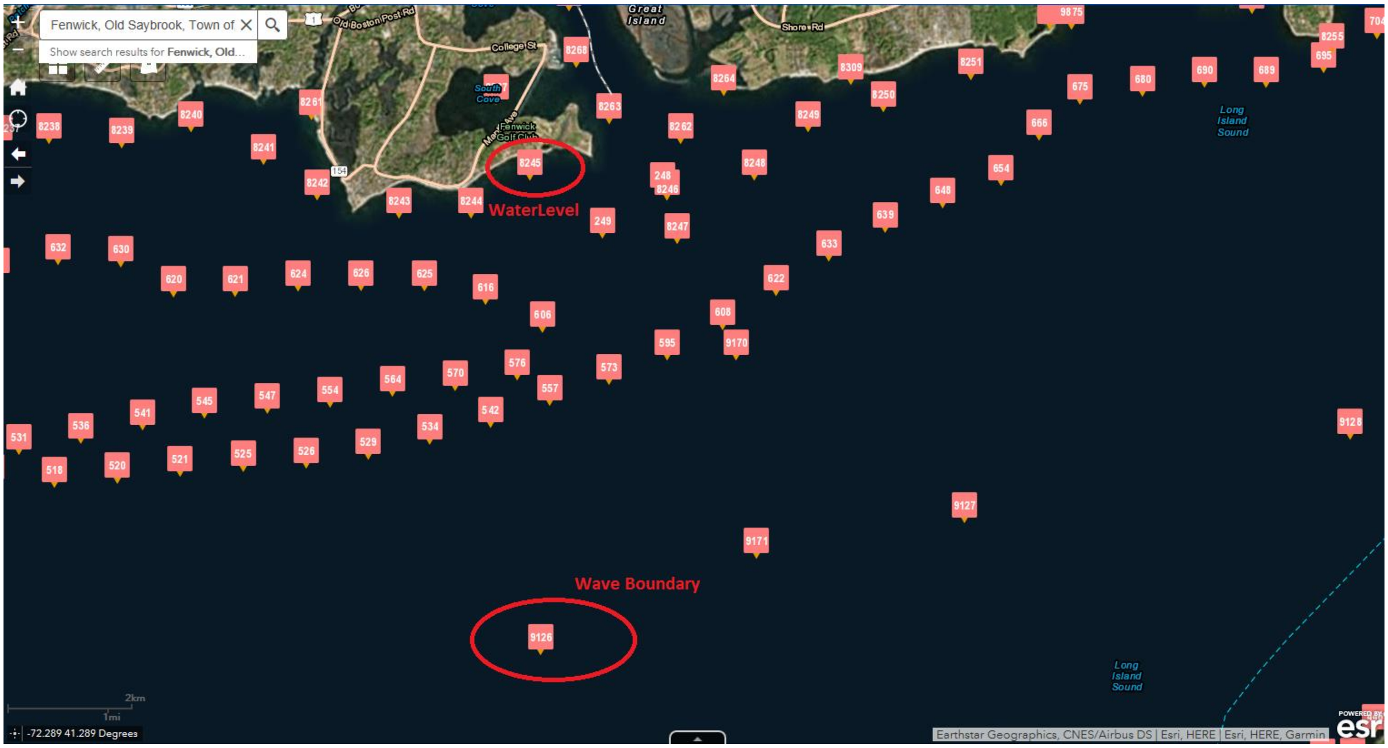
Appendix F – Numerical Water Level and Wave Modeling

As part of our ongoing Old Saybrook Community Coastal Resilience Study & Infrastructure Evaluation, GZA had already conducted broad scale regional numerical modeling of wave climatology and storm surge using SWAN. This provided financial benefits to the project as the numerical model for the site had already been prepared and only needed refinement of site specific coastal topographic and hydrographic features to complete model setup. The model mesh includes coarser detail hydrography offshore and much finer detail along the shoreline.



Model mesh created for SWAN included digitization of regional hydrography and topography

The next step of the modeling process includes selection of wave conditions and storm events to model. Because design of the living shoreline solution for this site will include elements to address high frequency low wave conditions and low frequency high wave conditions, our modeling team chose to simulate the predominant summer conditions with lower waves approaching from the southwest based on results of the statistical wind and wave analyses described previously and a series of storm events approaching from due south. The storm events chosen were based on research conducted by the United States Army Corps of Engineers (USACE) North Atlantic Comprehensive Coastal Study (NACCS) which conducted extensive numerical modeling and statistical analysis following Hurricane Sandy to determine probabilistic coastal storm and flood risks throughout the North Atlantic at individual points known as “save points”. At each one of these points, wave heights and storm surge water levels for the 1-year storm (100% probability of occurring each year) to the 10,000-year storm (0.01% chance of occurring each year) were calculated. The save points from the NACCS study located in the vicinity of the project are shown below. For this study, our modeling team chose to model the 2-year, 10-year and 100-year storm events. Table 1 includes the input parameters for each of the model scenarios run including wind speed, wind direction, water level, wave height and wave direction. Illustrations of modeling results for each of these scenarios are included below. On these illustrations, the extent of inundation is shown overlain on aerial photography as well as significant wave heights (with magnitudes shown as colors) and wave direction (shown as vectors).



Data from NACCS save points 8245 and 9126 were used to provide model input for simulated 2-year, 10-year and 100-year storms at the site.

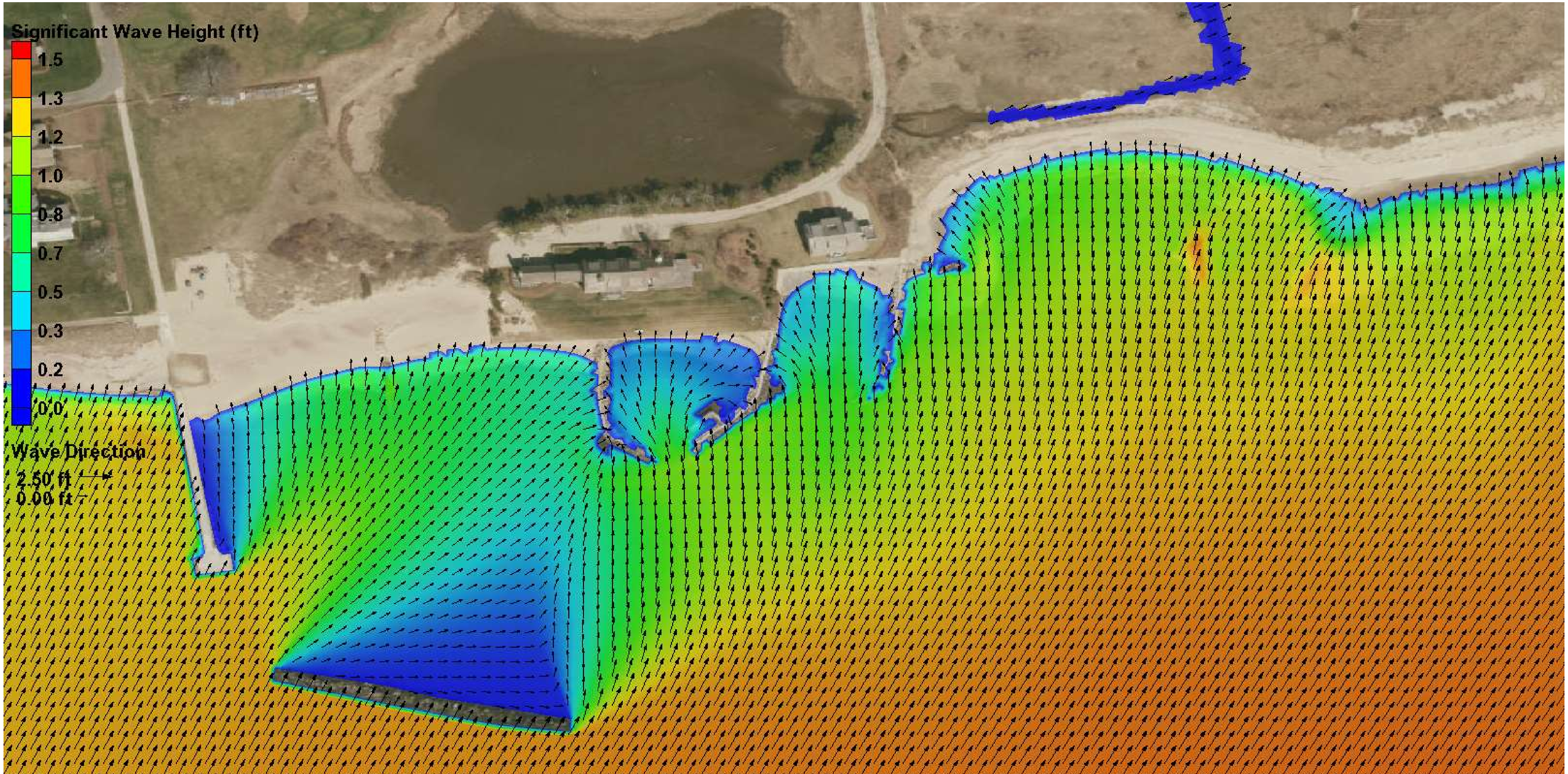
Table 1. SWAN Model Scenarios and Input Parameters

SWAN Modeling Scenario	Wind Speed[1] (mph)	Wind Direction[1]	Water Level[2] (El. NAVD88, ft)	Wave Height[3] (ft)	Wave Direction[3]
Prevailing Summer Conditions	16	WSW	1.5 (MHW)	2.5	WSW
2-Year Storm	35	S	4.8	8.3	S
10-Year Storm	56	S	6.7	10.4	S
100-Year Storm	72	S	9.4	11.9	S

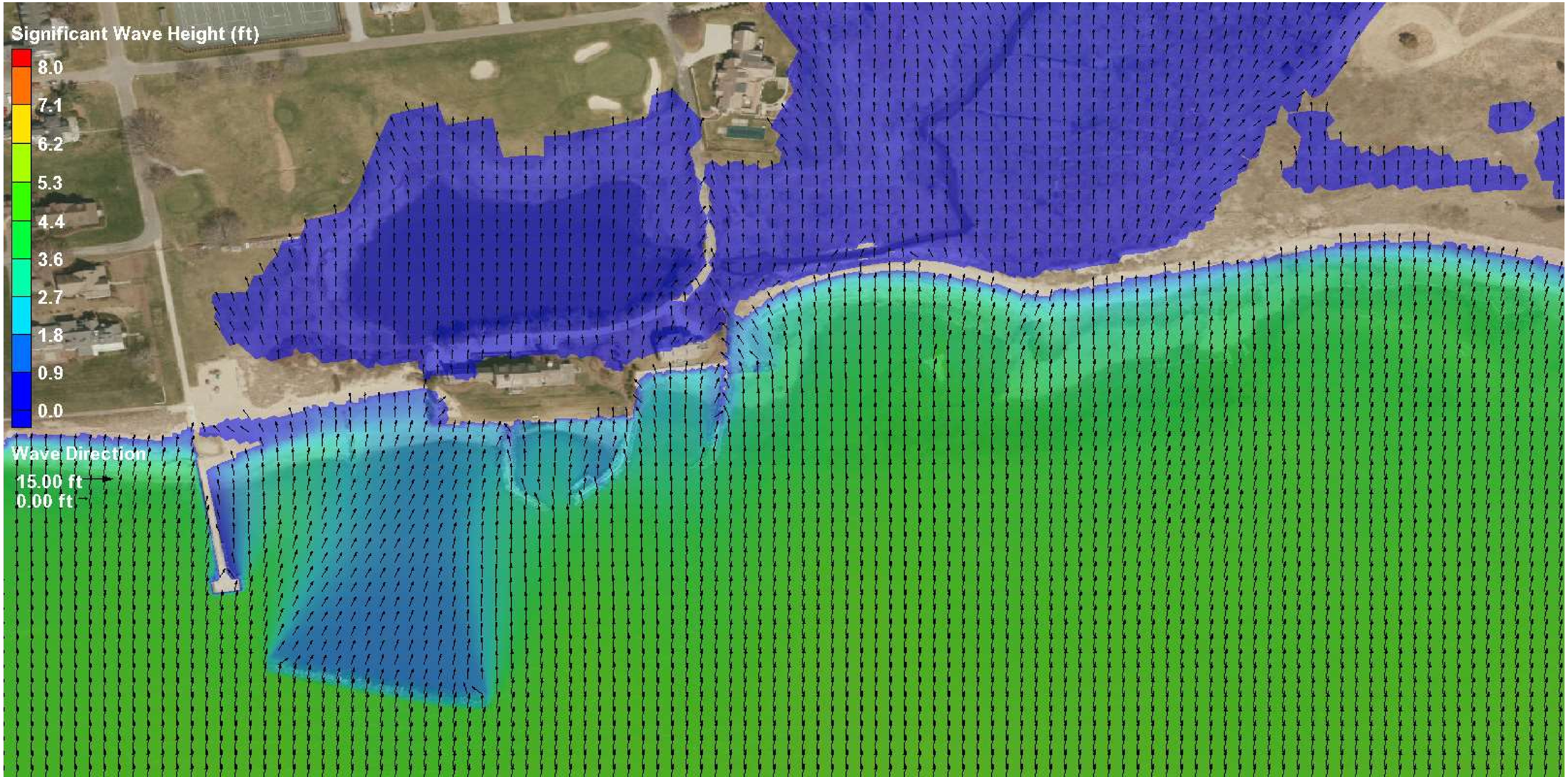
[1] *Based on GZA statistical analysis*

[2] *Based on USACE NACCS save point 8245*

[3] *Based on USACE NACCS save point 9126*



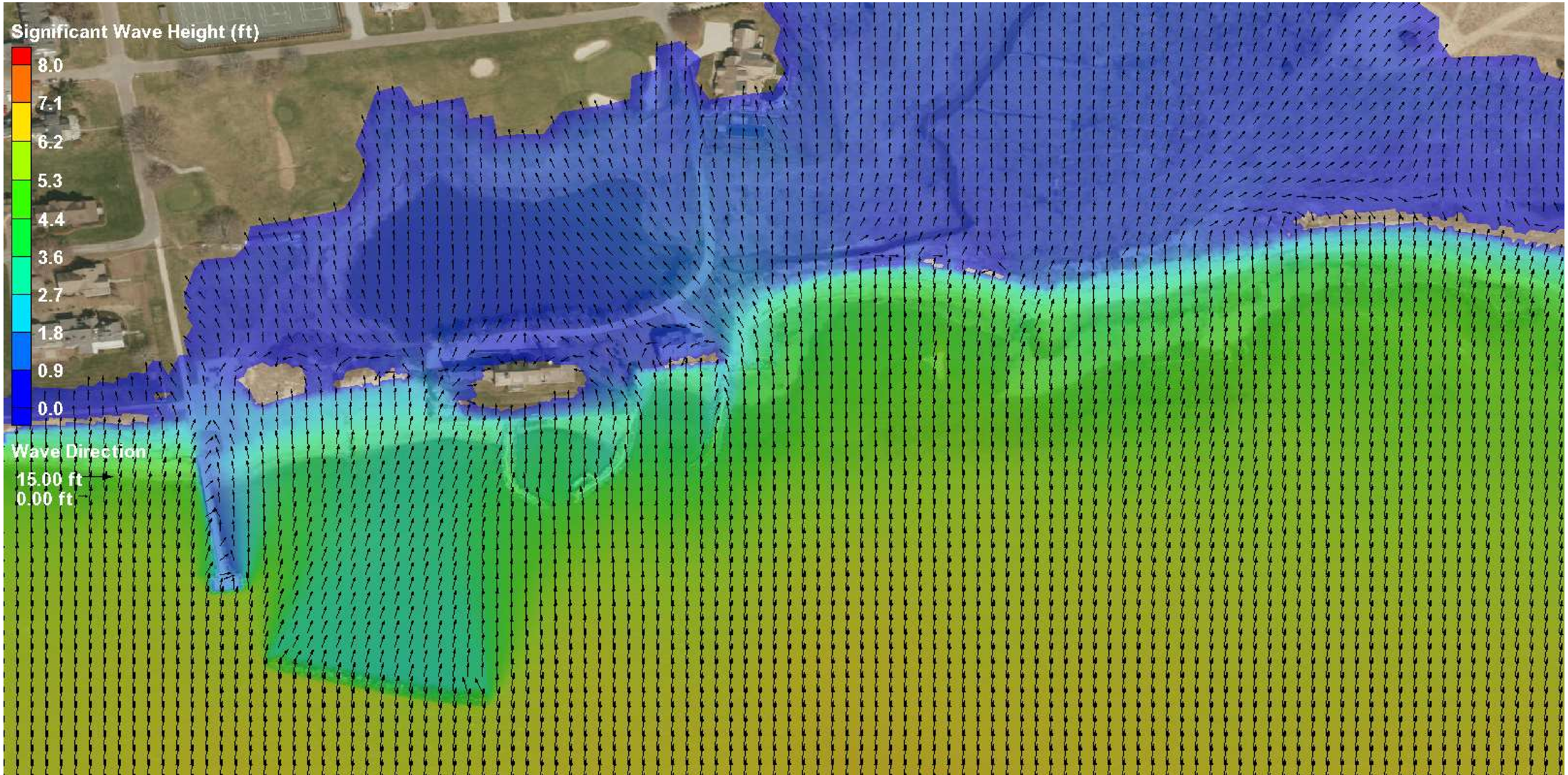
GZA Wave and Storm Surge Modeling
SWAN Scenario: Prevailing Conditions
Model Input: Wind Speed 16 mph | Wind Direction WSW | Water Level 1.5ft NAVD88 (MHW) | Wave Height 2.5ft | Wave Direction WSW



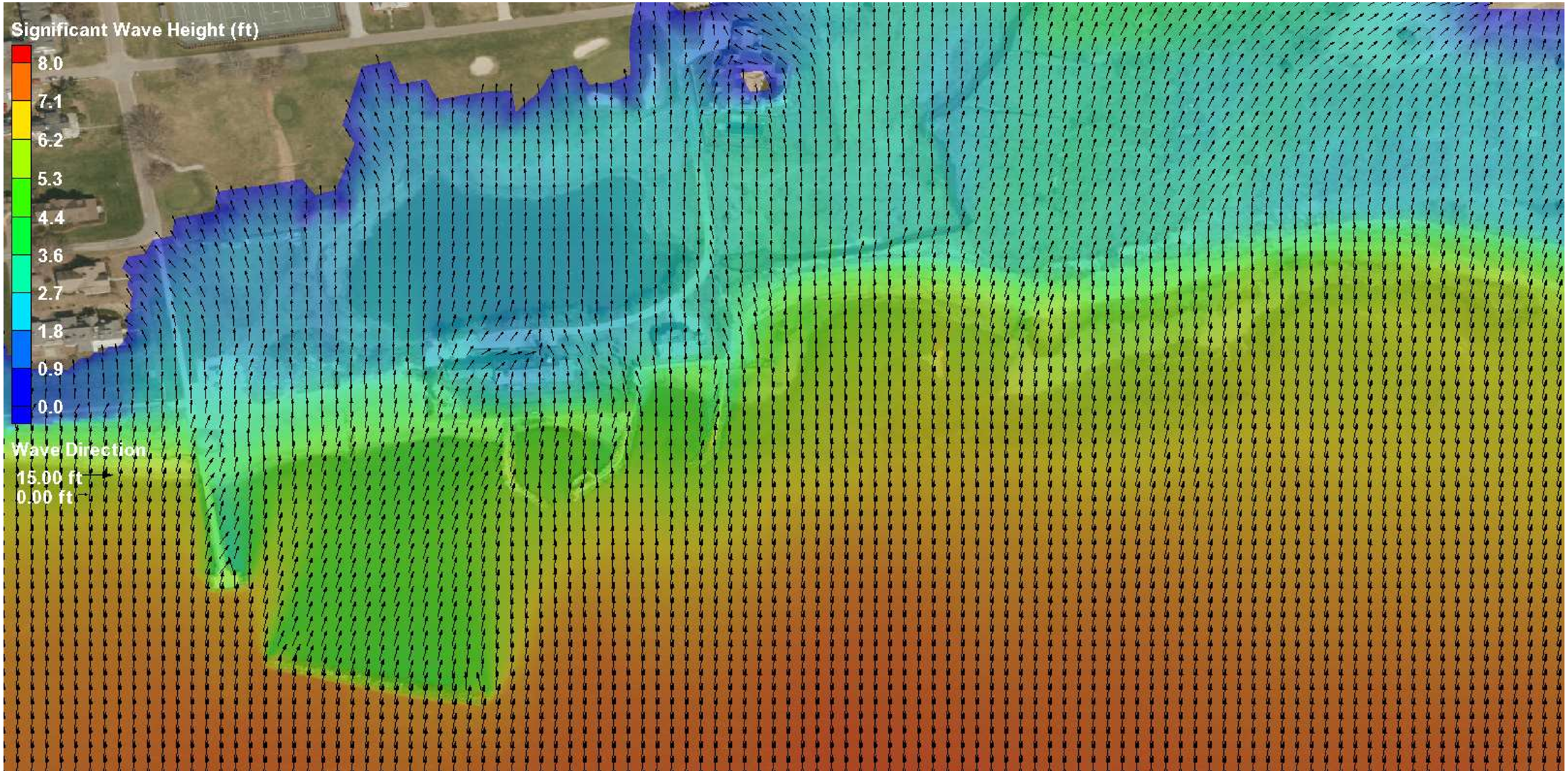
GZA Wave and Storm Surge Modeling

SWAN Scenario: 2-Year Storm

Model Input: Wind Speed 35 mph | Wind Direction S | Water Level 4.8ft NAVD88 | Wave Height 8.3ft | Wave Direction S



GZA Wave and Storm Surge Modeling
SWAN Scenario: 10-Year Storm
Model Input: Wind Speed 56 mph | Wind Direction S | Water Level 6.7ft NAVD88 | Wave Height 10.4ft | Wave Direction S



GZA Wave and Storm Surge Modeling
SWAN Scenario: 100-Year Storm
Model Input: Wind Speed 72 mph | Wind Direction S | Water Level 9.4ft NAVD88 | Wave Height 11.9ft | Wave Direction S

Appendix G – Alternative 5 Numerical Model Simulation Results

To refine the design and placement of the proposed stone sills, the conceptual layout was modeled in SWAN under predominant conditions experienced at the site as outlined in Appendix E. The goal in designing the stone sills is to create a wave energy environment landward of the sills in which a marsh environment can grow. Based on research described in this report, a significant wave height of under 0.5 feet under predominant conditions is necessary to sustain a marsh environment (indicated by areas of light to dark blue in SWAN modeling results). When the existing conditions were modeled (Figure 1), areas of existing marsh onsite fell within areas in which SWAN indicated significant wave heights were below this threshold.

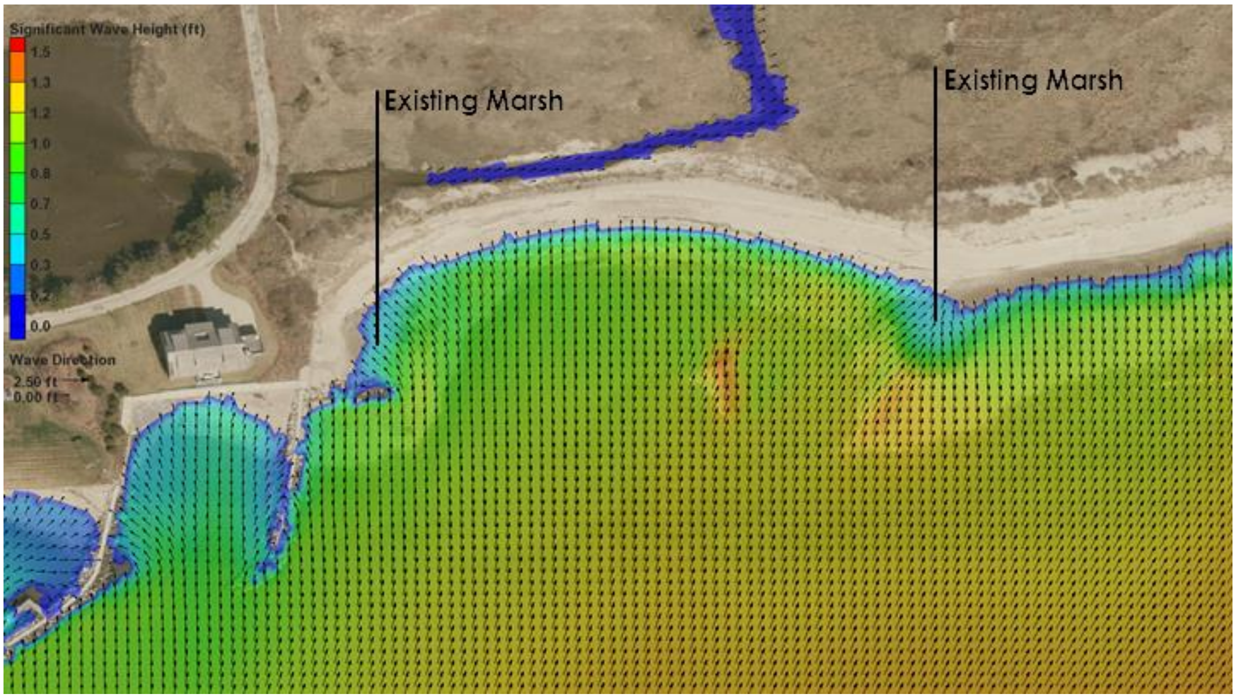


Figure 1. SWAN model of predominant wind and wave conditions under existing conditions (prior to dune breach) and location of existing marsh.

The conceptual layout and height of the proposed sills was then built into the SWAN mesh and the model was rerun under predominant conditions. Results of this model simulation are shown in Figure 2. These results indicated the conceptual alignment of the sills would potentially allow too much wave energy into the marsh environment through the proposed structure gaps pushing the significant wave height above the 0.5 m threshold for marsh growth.

Based on these results, the alignment and overlap of the proposed sills were refined (as shown in Figure 3) and the model simulation was rerun. Crest elevations of the sills remained unchanged, seaward sills were shifted slightly offshore and theirs lengths were increased to create wider overlap zones between seaward and landward sills. These results indicated a more effective dampening of wave energy from this sill configuration resulting in most areas landward of the proposed sills falling below the research-based threshold for marsh growth based on significant wave height. Further refinement of the sill configuration is underway to address isolated areas of higher wave energy indicated by this model at the first, second, fourth and eighth gaps from the west.

Model results also present wave heights post construction were almost identical to existing conditions for locations outside of the project area. The results completed to-date indicate that construction of sills are not likely to have significant impacts on wave climate along adjacent shorelines.

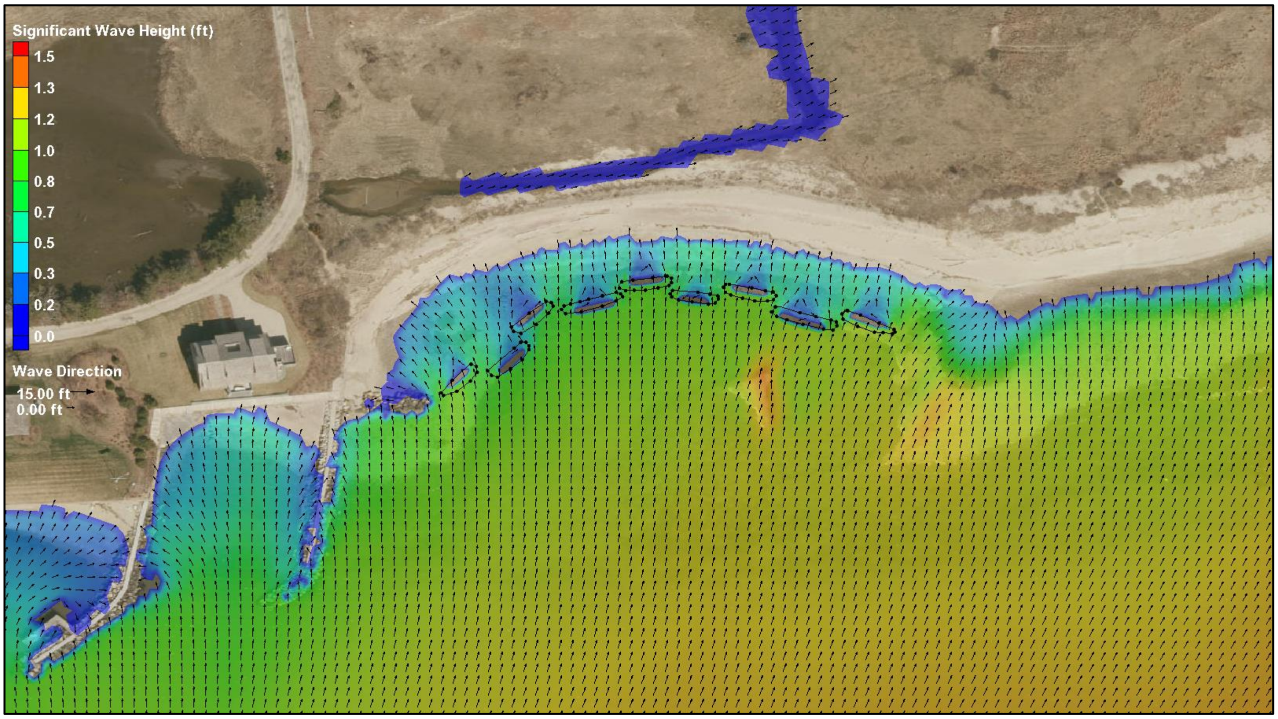


Figure 2. SWAN model of predominant wind and wave conditions for preliminary sill design and layout prior to revision.

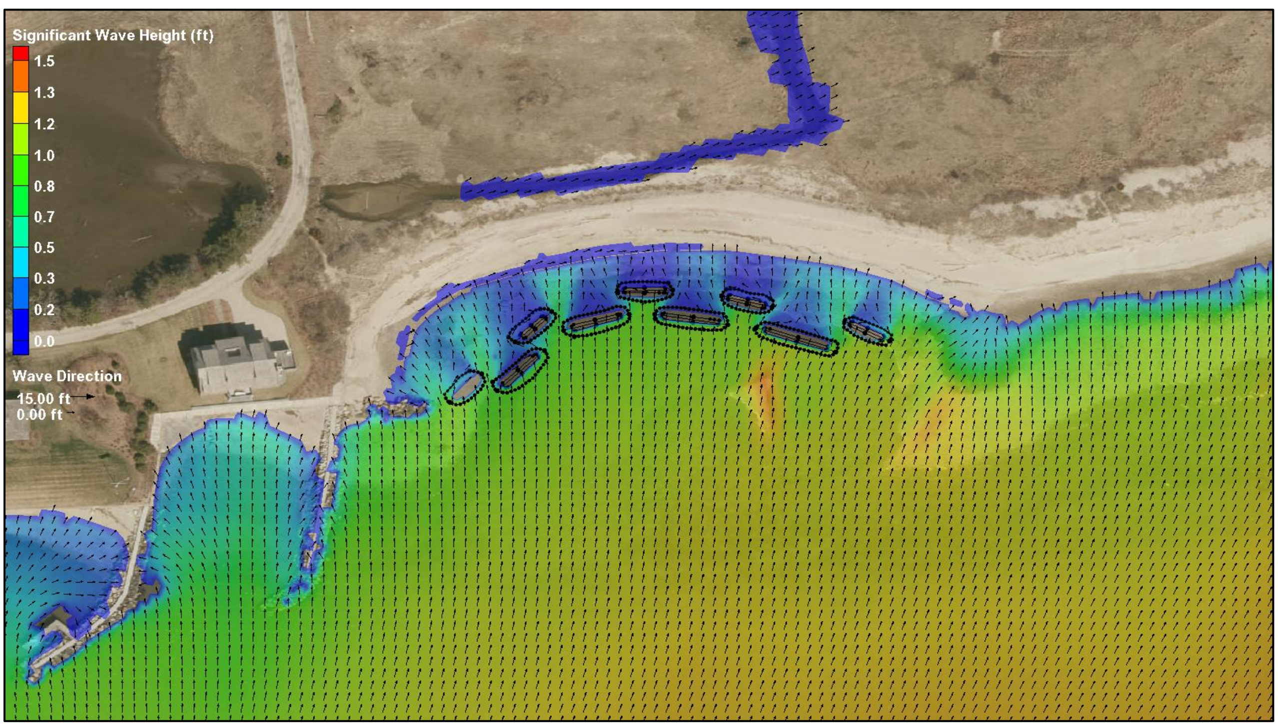


Figure 3. SWAN model of predominant wind and wave conditions for preliminary sill design and layout following revision based on SWAN results.

Appendix H – Representative Project Presentation

Proactive By Design.
Our Company Commitment

Hepburn Preserve
Living Shoreline Project

Borough of Fenwick, Connecticut

Hande McCaw | Project Manager | Coastal Engineer
Steve Lecco | Natural Resources & Permitting Specialist

GZA GeoEnvironmental, Inc.

Hepburn Preserve Living Shoreline Project
Borough of Fenwick, Connecticut

Lynde Point Marsh Restoration

Date: 2004-2006

Partners: Lynde Point Land Trust, CT DEEP, Ducks Unlimited

Project: 10-acre restoration including removal of 60,000 CY of dredge material placed in 1940's

Restored Habitat: tidal wetlands, open water, panne, brackish meadow

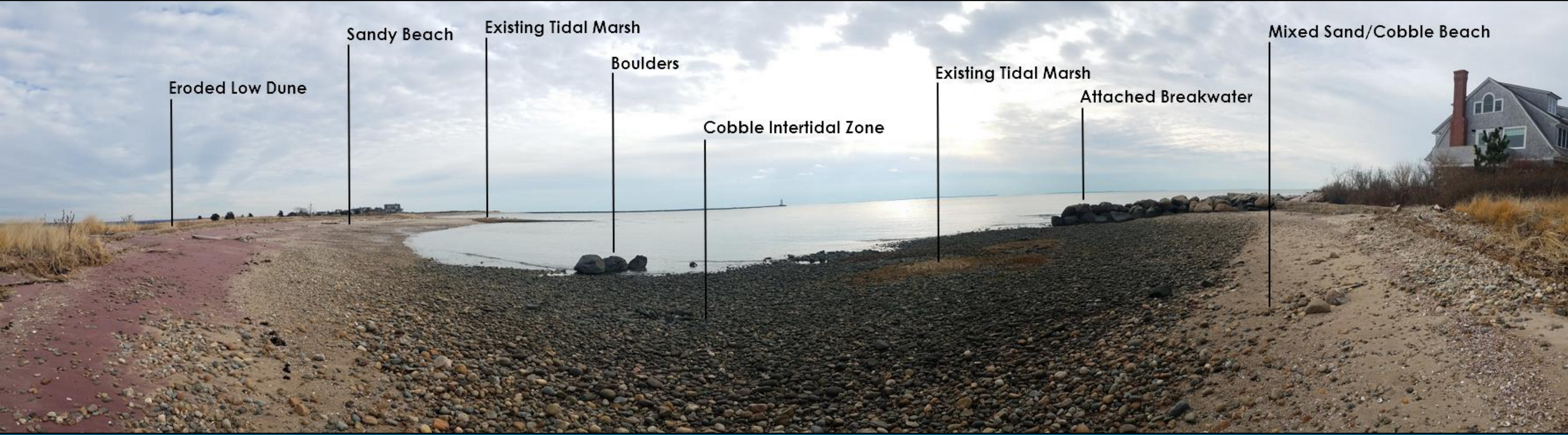
Species Benefits: migratory waterfowl, wading birds, shorebirds, nesting passerines, diamondback terrapin


2006
Concern over
Beach & Dune Erosion

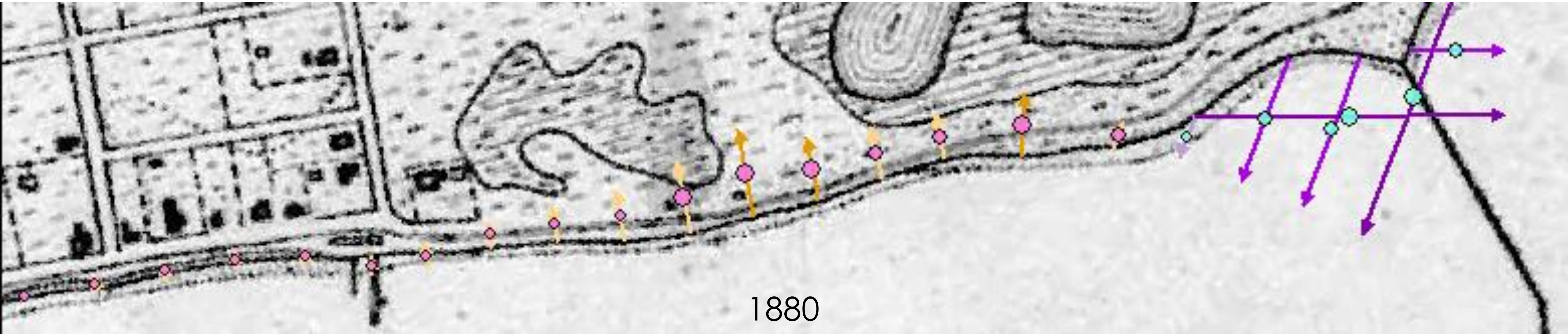
Dune Restoration 2007-2008

Hurricane Irene (2011)
Superstorm Sandy (2012)

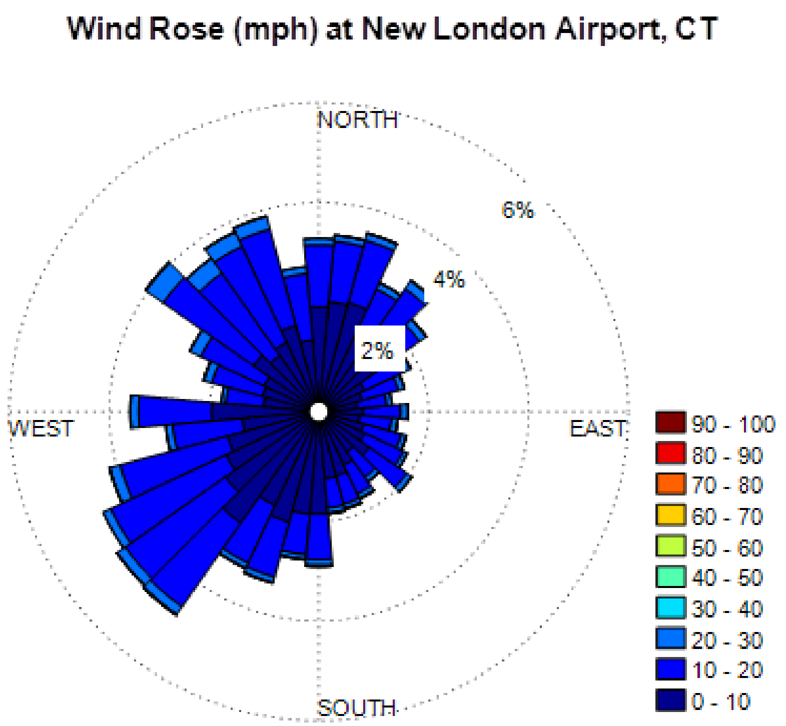

High Tide Line
Attached Breakwater
Eroded Low Dune
Restored Lynde Point Marsh
Crab Creek
Storm Overwash Sediment

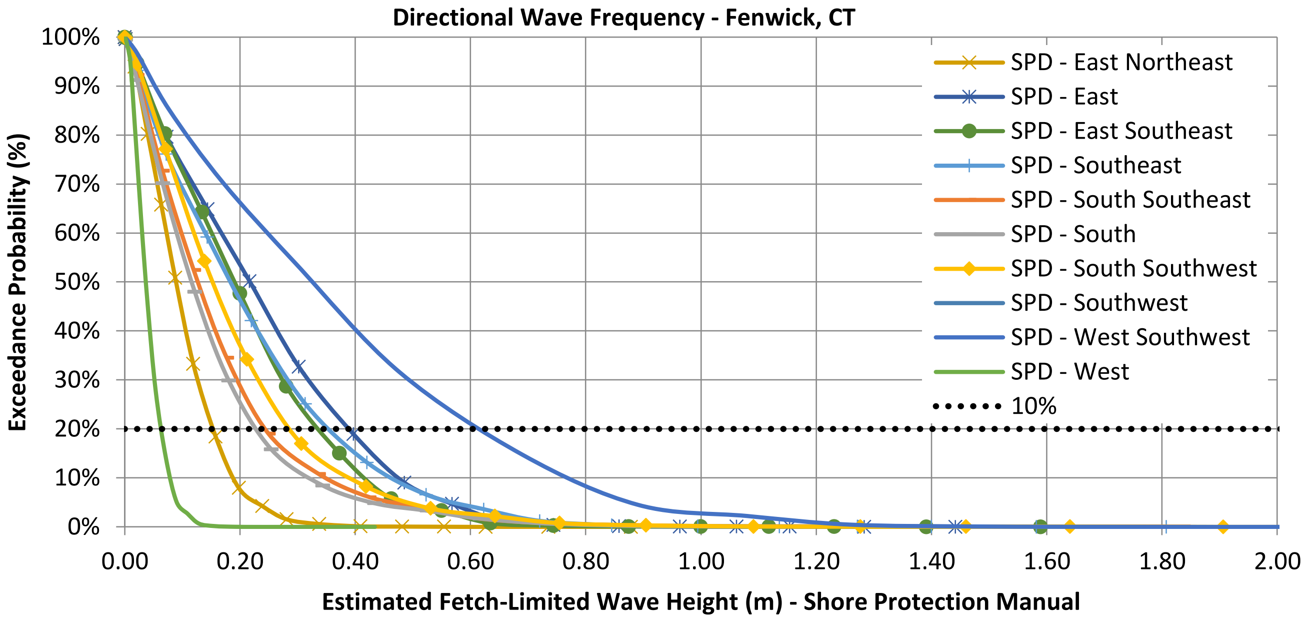

Sandy Beach
Existing Tidal Marsh
Eroded Low Dune
Boulders
Cobble Intertidal Zone
Existing Tidal Marsh
Attached Breakwater
Mixed Sand/Cobble Beach

Historical Shoreline Change Analysis 1880-2012 (UCONN CLEAR)



Analysis of Site Wind, Wave and Water Level Conditions



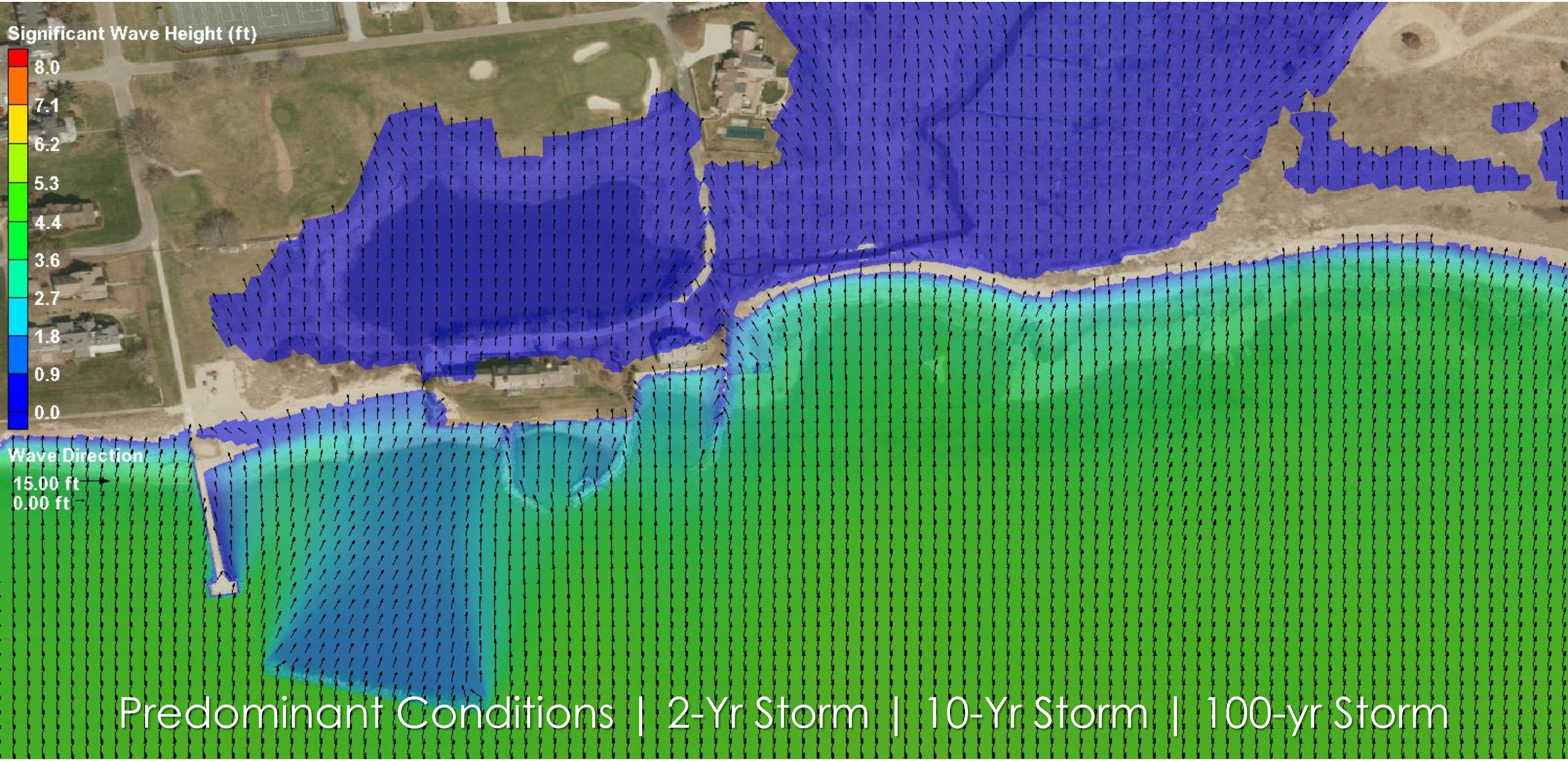


Projected Old Saybrook Tidal Datums Based on USACE High RSLC Projections

Current Datum	Feet (NAVD88)	2040 (USACE High SLR)	2070 (USACE High SLR)	2100 (USACE High SLR)
MSL	-0.28 (-0.31)	0.51	2.14	4.43
MHW	1.14 (1.47)	2.12	4.14	6.98
MHHW	1.5 (1.76)	2.48	4.50	7.34
MLW	-2.06 (-2.10)	-1.08	0.96	3.83
MLLW	-2.3 (-2.30)	-1.31	0.73	3.59

*Tidal datums at the exact project site differ somewhat than Old Saybrook and are shown above in parenthesis.

Numerical Modeling of Waves and Water Levels (SWAN)



Predominant Conditions | 2-Yr Storm | 10-Yr Storm | 100-yr Storm

Living Shoreline Design Objectives

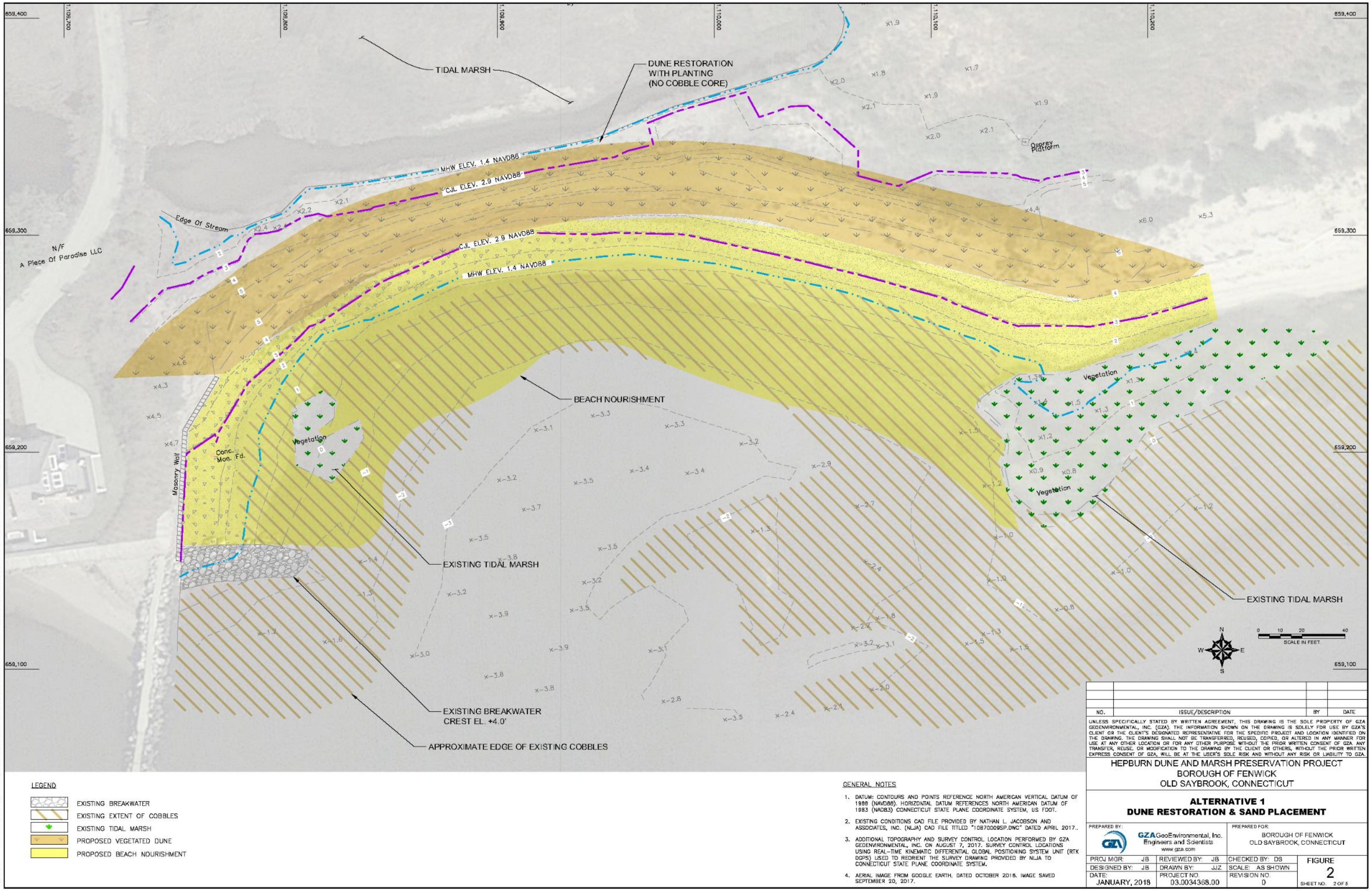
1. Mitigate on-going shoreline erosion
2. Maintain natural aesthetic
3. Reduce the probability of a breach of the barrier spit
4. Protect the Lynde Point Marsh
5. **Enhance the existing habitat**
6. Avoid additional, significant disruption of natural coastal processes
7. Provide a range of costs, permitting timelines and levels of protection to consider

What is a Living Shoreline?

Connecticut's Definition:

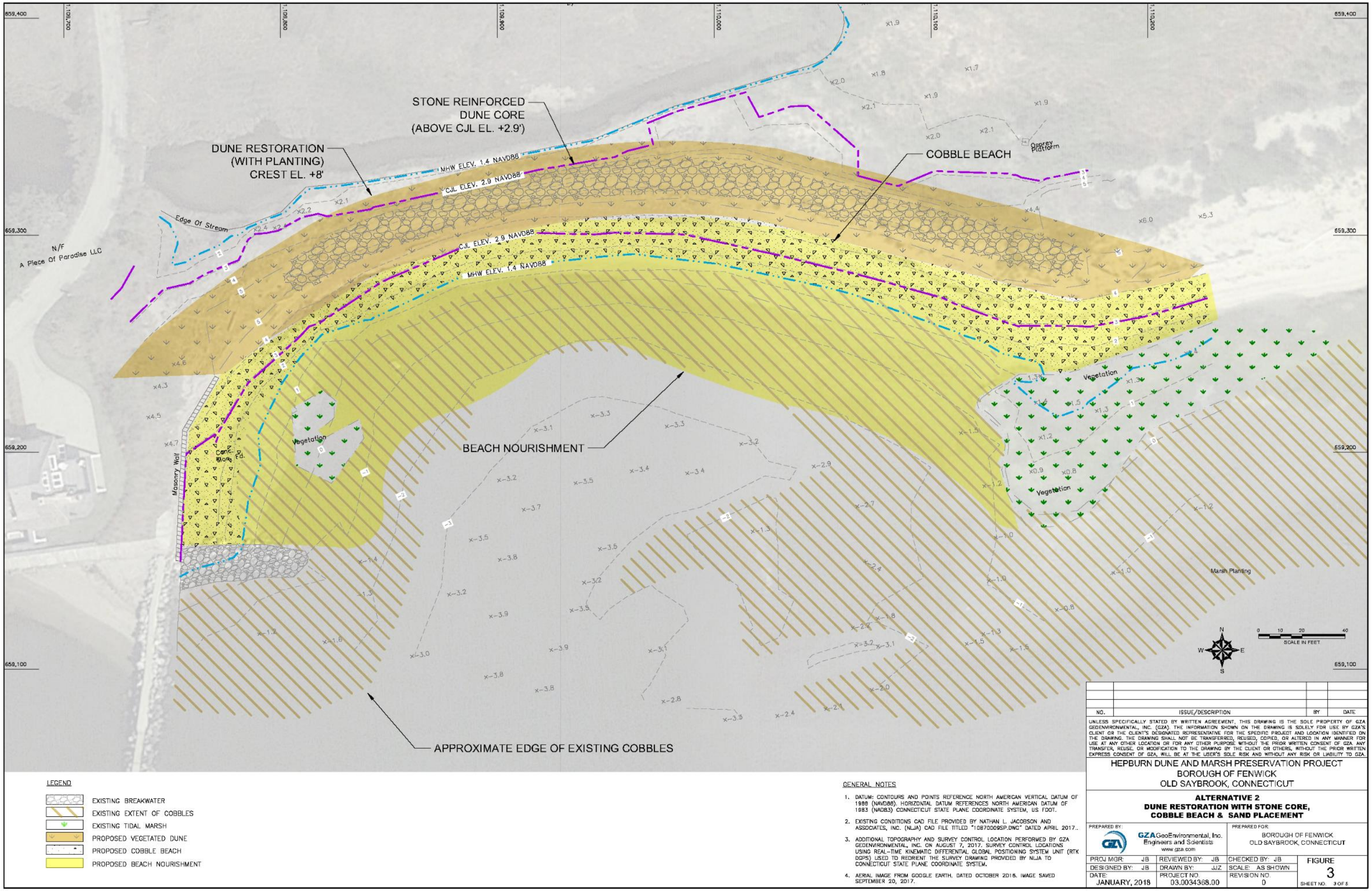
A shoreline erosion control management practice which also restores, enhances, maintains or creates natural coastal or riparian habitat, functions and processes. Coastal and riparian habitats include but are not limited to intertidal flats, tidal marsh, beach/dune systems, and bluffs. ***<u>Living shorelines may include structural features that are combined with natural components to attenuate wave energy and currents.</u>***

Alt. 1



TIDAL MARSH
DUNE RESTORATION WITH PLANTING (NO COBBLE CORE)
MHW ELEV. 1.4 NAVD88
CJL ELEV. 2.9 NAVD88
Edge Of Stream
N/F A Piece Of Paradise LLC
Osprey Platform
Vegetation
BEACH NOURISHMENT
Conc. Mon. Fd.
Masonry Wall
EXISTING TIDAL MARSH
EXISTING BREAKWATER CREST EL. +4.0'
APPROXIMATE EDGE OF EXISTING COBBLES
SCALE IN FEET
LEGEND
EXISTING BREAKWATER
EXISTING EXTENT OF COBBLES
EXISTING TIDAL MARSH
PROPOSED VEGETATED DUNE
PROPOSED BEACH NOURISHMENT
GENERAL NOTES
1. DATUM: CONTOURS AND POINTS REFERENCE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88). HORIZONTAL DATUM REFERENCES NORTH AMERICAN DATUM OF 1983 (NAD83) CONNECTICUT STATE PLANE COORDINATE SYSTEM, US FOOT.
2. EXISTING CONDITIONS CAD FILE PROVIDED BY NATHAN L. JACOBSON AND ASSOCIATES, INC. (NLJA) CAD FILE TITLED "10870009SP.DWG" DATED APRIL 2017..
3. ADDITIONAL TOPOGRAPHY AND SURVEY CONTROL LOCATION PERFORMED BY GZA GEOENVIRONMENTAL, INC. ON AUGUST 7, 2017. SURVEY CONTROL LOCATIONS USING REAL-TIME KINEMATIC DIFFERENTIAL GLOBAL POSITIONING SYSTEM UNIT (RTK DGPS) USED TO REORIENT THE SURVEY DRAWING PROVIDED BY NLJA TO CONNECTICUT STATE PLANE COORDINATE SYSTEM.
4. AERIAL IMAGE FROM GOOGLE EARTH, DATED OCTOBER 2016. IMAGE SAVED SEPTEMBER 20, 2017.
NO. ISSUE/DESCRIPTION BY DATE
HEPBURN DUNE AND MARSH PRESERVATION PROJECT
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT
ALTERNATIVE 1
DUNE RESTORATION & SAND PLACEMENT
PREPARED BY: GZA GeoEnvironmental, Inc. Engineers and Scientists www.gza.com
PREPARED FOR: BOROUGH OF FENWICK OLD SAYBROOK, CONNECTICUT
PROJ MGR: JB
REVIEWED BY: JB
CHECKED BY: DS
DESIGNED BY: JB
DRAWN BY: JJZ
SCALE: AS SHOWN
DATE: JANUARY, 2018
PROJECT NO. 03.0034368.00
REVISION NO. 0
FIGURE 2
SHEET NO. 2 OF 5

Alt. 2


STONE REINFORCED DUNE CORE (ABOVE CJL EL. +2.9')
DUNE RESTORATION (WITH PLANTING) CREST EL. +8'
COBBLE BEACH
MHW ELEV. 1.4 NAVD88
CJL ELEV. 2.9 NAVD88
Edge Of Stream
N/F A Piece Of Paradise LLC
Osprey Platform
Vegetation
Masonry Wall
BEACH NOURISHMENT
APPROXIMATE EDGE OF EXISTING COBBLES
Marsh Planting
SCALE IN FEET
LEGEND
EXISTING BREAKWATER
EXISTING EXTENT OF COBBLES
EXISTING TIDAL MARSH
PROPOSED VEGETATED DUNE
PROPOSED COBBLE BEACH
PROPOSED BEACH NOURISHMENT
GENERAL NOTES
1. DATUM: CONTOURS AND POINTS REFERENCE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88). HORIZONTAL DATUM REFERENCES NORTH AMERICAN DATUM OF 1983 (NAD83) CONNECTICUT STATE PLANE COORDINATE SYSTEM, US FOOT.
2. EXISTING CONDITIONS CAD FILE PROVIDED BY NATHAN L. JACOBSON AND ASSOCIATES, INC. (NLJA) CAD FILE TITLED "10870009SP.DWG" DATED APRIL 2017..
3. ADDITIONAL TOPOGRAPHY AND SURVEY CONTROL LOCATION PERFORMED BY GZA GEOENVIRONMENTAL, INC. ON AUGUST 7, 2017. SURVEY CONTROL LOCATIONS USING REAL-TIME KINEMATIC DIFFERENTIAL GLOBAL POSITIONING SYSTEM UNIT (RTK DGPS) USED TO REORIENT THE SURVEY DRAWING PROVIDED BY NLJA TO CONNECTICUT STATE PLANE COORDINATE SYSTEM.
4. AERIAL IMAGE FROM GOOGLE EARTH, DATED OCTOBER 2016. IMAGE SAVED SEPTEMBER 20, 2017.
NO. ISSUE/DESCRIPTION BY DATE
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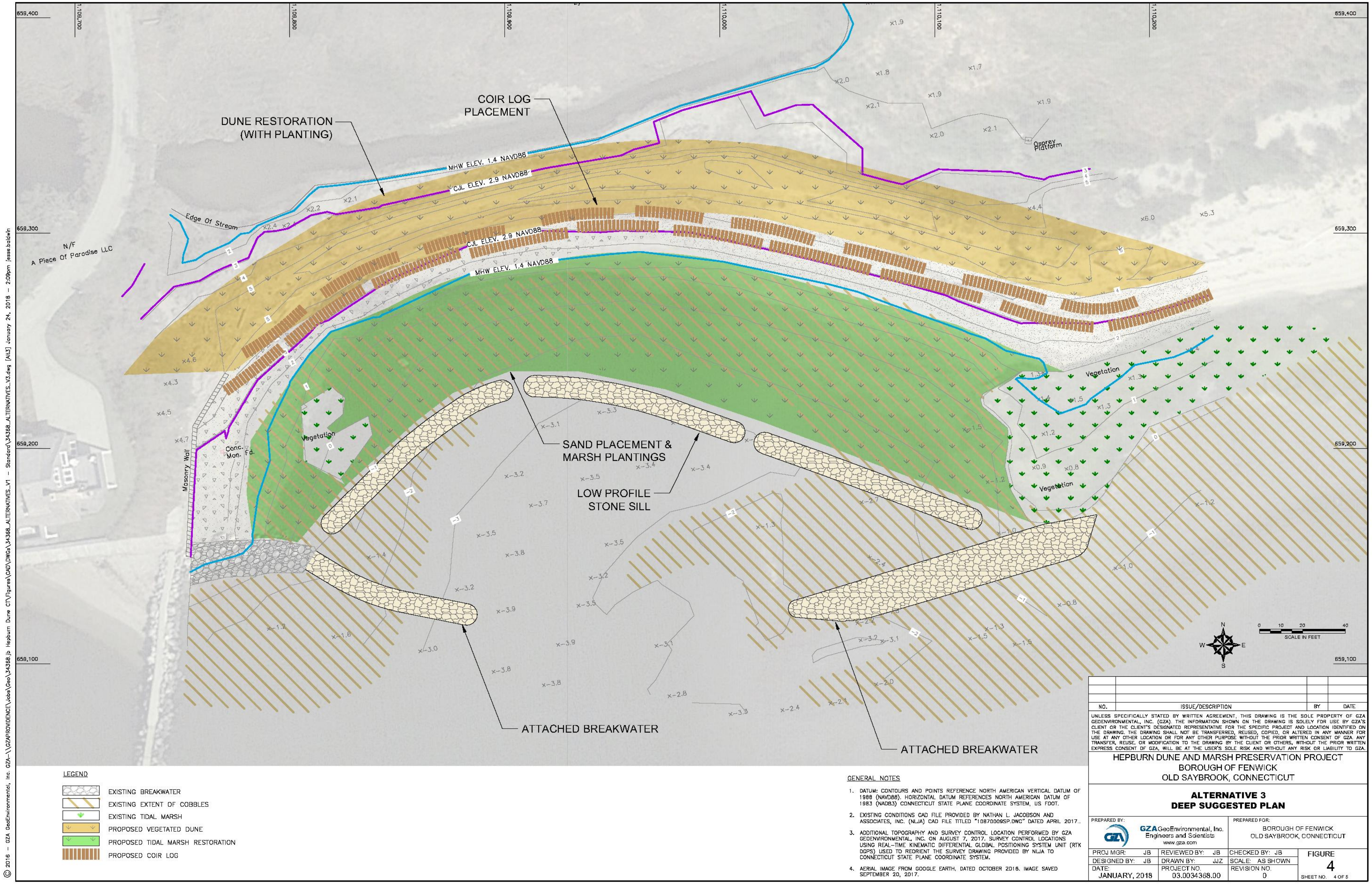
HEPBURN DUNE AND MARSH PRESERVATION PROJECT
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT
ALTERNATIVE 2
DUNE RESTORATION WITH STONE CORE, COBBLE BEACH & SAND PLACEMENT
PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com
PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT
PROJ MGR: JB
REVIEWED BY: JB
CHECKED BY: JB
DESIGNED BY: JB
DRAWN BY: JJZ
SCALE: AS SHOWN
DATE: JANUARY, 2018
PROJECT NO. 03.0034368.00
REVISION NO. 0
FIGURE 3
SHEET NO. 3 OF 5

Alt. 3
DEEP



DUNE RESTORATION (WITH PLANTING)
COIR LOG PLACEMENT
MHW ELEV. 1.4 NAVD88
CJL ELEV. 2.9 NAVD88
Edge Of Stream
N/F A Piece Of Paradise LLC
Osprey Platform
Vegetation
Conc. Mon. Fd.
Masonry Wall
SAND PLACEMENT & MARSH PLANTINGS
LOW PROFILE STONE SILL
ATTACHED BREAKWATER
ATTACHED BREAKWATER
SCALE IN FEET
LEGEND
EXISTING BREAKWATER
EXISTING EXTENT OF COBBLES
EXISTING TIDAL MARSH
PROPOSED VEGETATED DUNE
PROPOSED TIDAL MARSH RESTORATION
PROPOSED COIR LOG
GENERAL NOTES
1. DATUM: CONTOURS AND POINTS REFERENCE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88). HORIZONTAL DATUM REFERENCES NORTH AMERICAN DATUM OF 1983 (NAD83) CONNECTICUT STATE PLANE COORDINATE SYSTEM, US FOOT.
2. EXISTING CONDITIONS CAD FILE PROVIDED BY NATHAN L. JACOBSON AND ASSOCIATES, INC. (NLJA) CAD FILE TITLED "10870009SP.DWG" DATED APRIL 2017..
3. ADDITIONAL TOPOGRAPHY AND SURVEY CONTROL LOCATION PERFORMED BY GZA GEOENVIRONMENTAL, INC. ON AUGUST 7, 2017. SURVEY CONTROL LOCATIONS USING REAL-TIME KINEMATIC DIFFERENTIAL GLOBAL POSITIONING SYSTEM UNIT (RTK DGPS) USED TO REORIENT THE SURVEY DRAWING PROVIDED BY NLJA TO CONNECTICUT STATE PLANE COORDINATE SYSTEM.
4. AERIAL IMAGE FROM GOOGLE EARTH, DATED OCTOBER 2016. IMAGE SAVED SEPTEMBER 20, 2017.
NO. ISSUE/DESCRIPTION BY DATE
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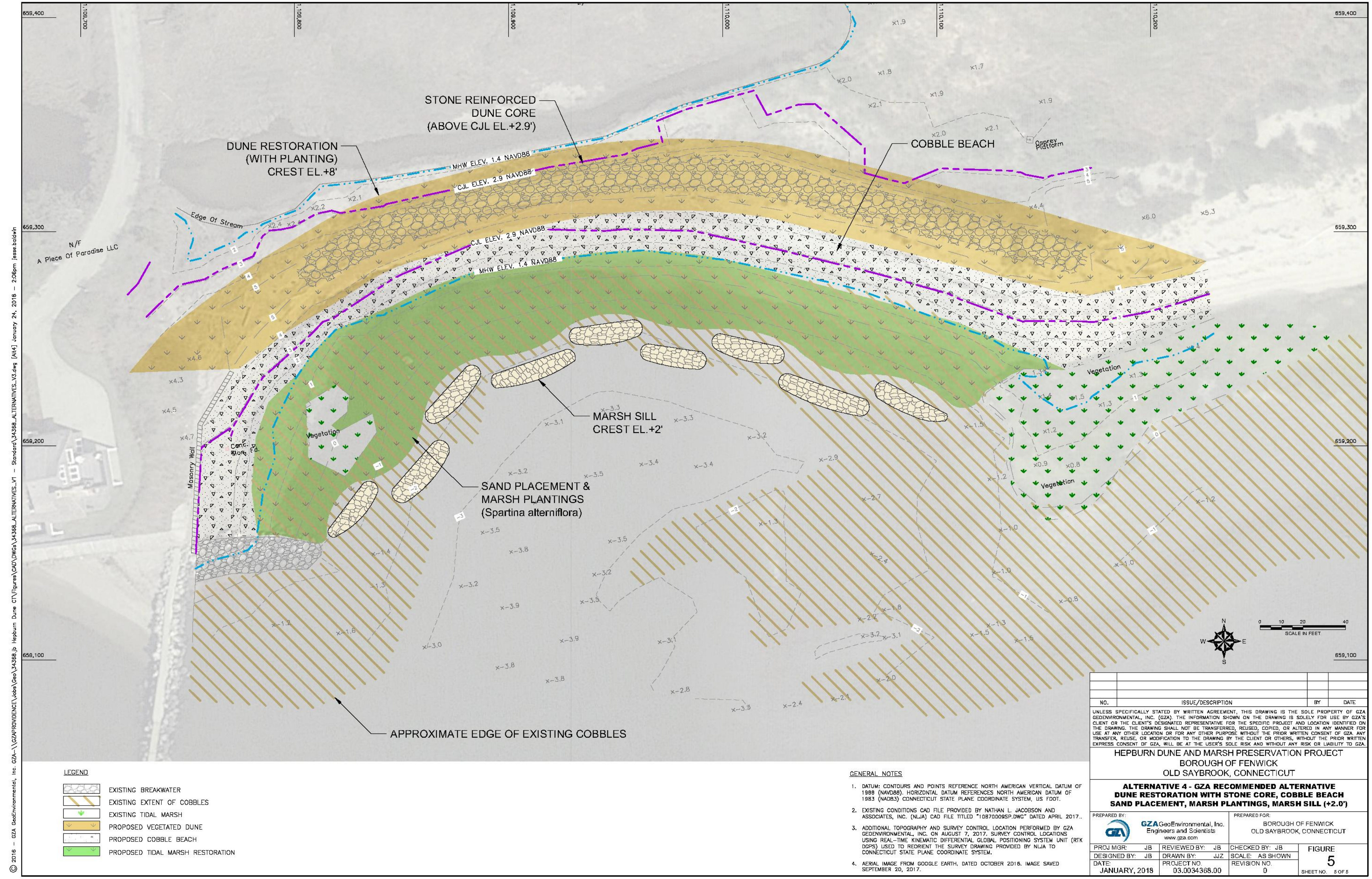
HEPBURN DUNE AND MARSH PRESERVATION PROJECT
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT
ALTERNATIVE 3
DEEP SUGGESTED PLAN
PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com
PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT
PROJ MGR: JB
REVIEWED BY: JB
CHECKED BY: JB
DESIGNED BY: JB
DRAWN BY: JJZ
SCALE: AS SHOWN
DATE: JANUARY, 2018
PROJECT NO. 03.0034368.00
REVISION NO. 0
FIGURE 4
SHEET NO. 4 OF 5

Alt. 4


STONE REINFORCED DUNE CORE (ABOVE CJL EL.+2.9')
DUNE RESTORATION (WITH PLANTING) CREST EL.+8'
COBBLE BEACH
MHW ELEV. 1.4 NAVD88
CJL ELEV. 2.9 NAVD88
Edge Of Stream
N/F A Piece Of Paradise LLC
Osprey Platform
Vegetation
Masonry Wall
MARSH SILL CREST EL.+2'
SAND PLACEMENT & MARSH PLANTINGS (Spartina alterniflora)
APPROXIMATE EDGE OF EXISTING COBBLES
659,400
659,300
659,200
659,100
N
W
E
S
SCALE IN FEET
0
10
20
40
LEGEND
EXISTING BREAKWATER
EXISTING EXTENT OF COBBLES
EXISTING TIDAL MARSH
PROPOSED VEGETATED DUNE
PROPOSED COBBLE BEACH
PROPOSED TIDAL MARSH RESTORATION
GENERAL NOTES
1. DATUM: CONTOURS AND POINTS REFERENCE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88). HORIZONTAL DATUM REFERENCES NORTH AMERICAN DATUM OF 1983 (NAD83) CONNECTICUT STATE PLANE COORDINATE SYSTEM, US FOOT.
2. EXISTING CONDITIONS CAD FILE PROVIDED BY NATHAN L. JACOBSON AND ASSOCIATES, INC. (NLJA) CAD FILE TITLED "10870009SP.DWG" DATED APRIL 2017..
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4. AERIAL IMAGE FROM GOOGLE EARTH, DATED OCTOBER 2016. IMAGE SAVED SEPTEMBER 20, 2017.
NO.
ISSUE/DESCRIPTION
BY
DATE
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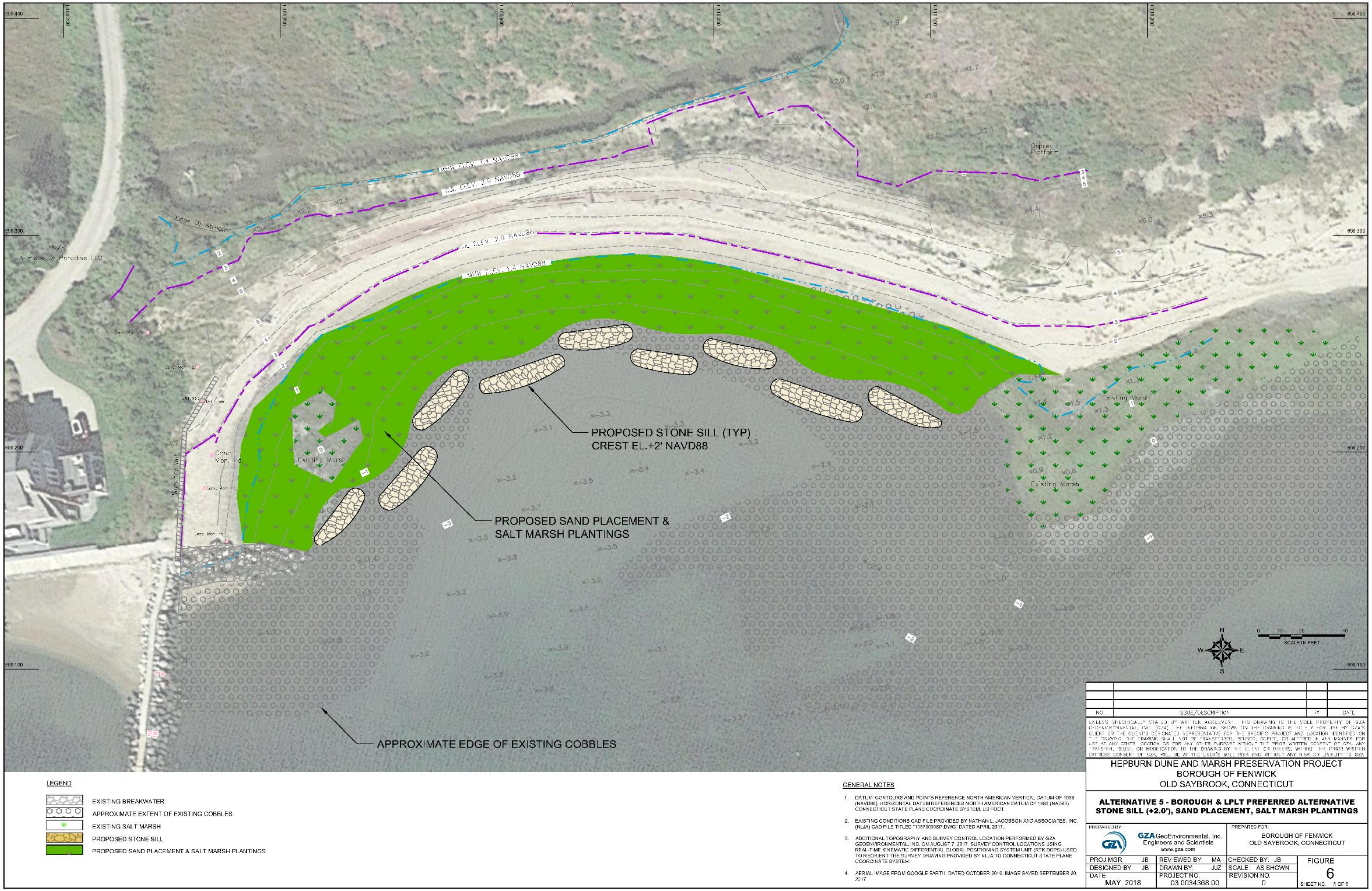
HEPBURN DUNE AND MARSH PRESERVATION PROJECT
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT
ALTERNATIVE 4 - GZA RECOMMENDED ALTERNATIVE
DUNE RESTORATION WITH STONE CORE, COBBLE BEACH
SAND PLACEMENT, MARSH PLANTINGS, MARSH SILL (+2.0')
PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com
PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT
PROJ MGR: JB
REVIEWED BY: JB
CHECKED BY: JB
DESIGNED BY: JB
DRAWN BY: JJZ
SCALE: AS SHOWN
DATE: JANUARY, 2018
PROJECT NO. 03.0034368.00
REVISION NO. 0
FIGURE 5
SHEET NO. 5 OF 5

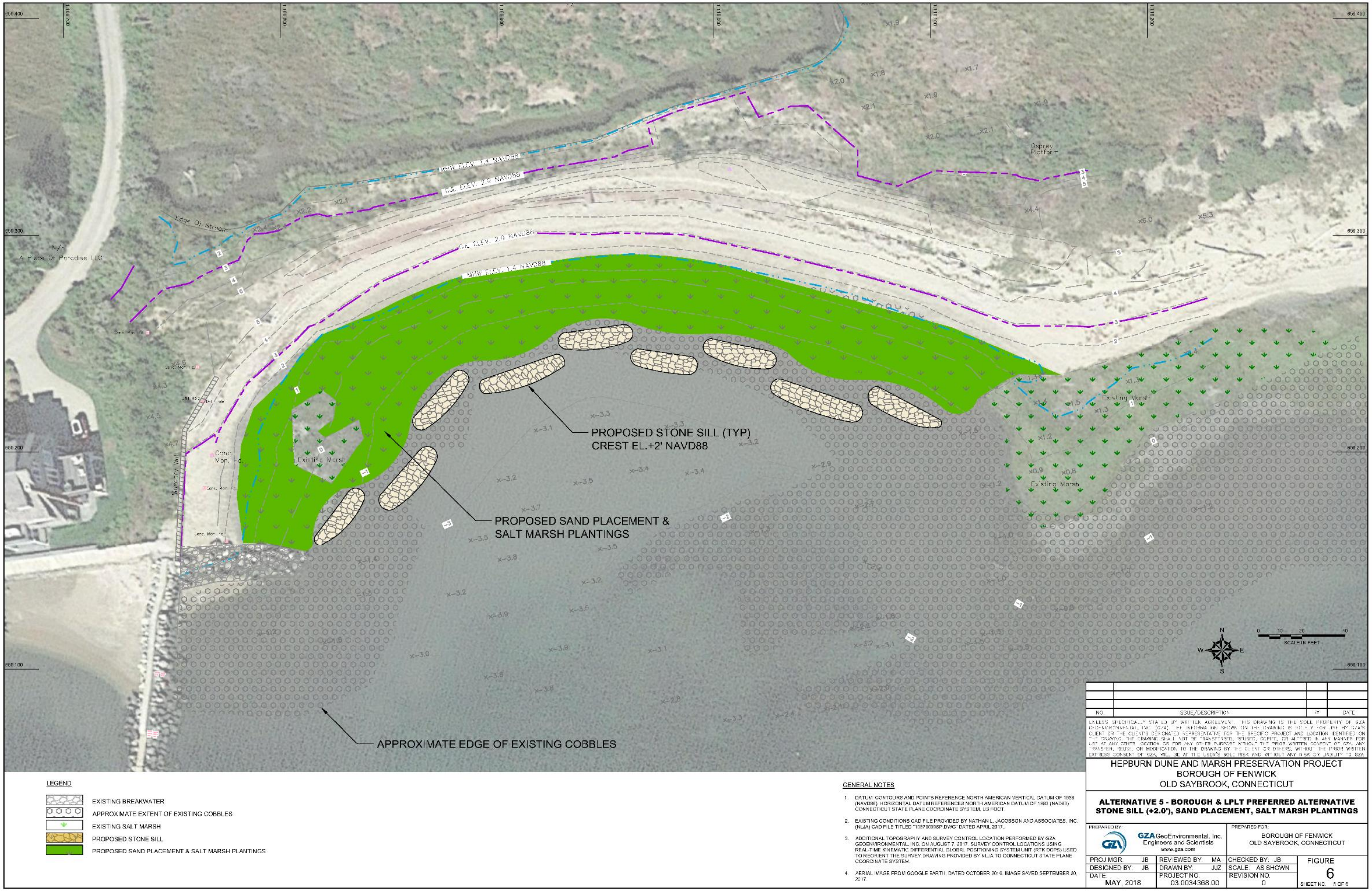
Alt. 5

Marsh Sills
Marsh Creation



Alt. 5

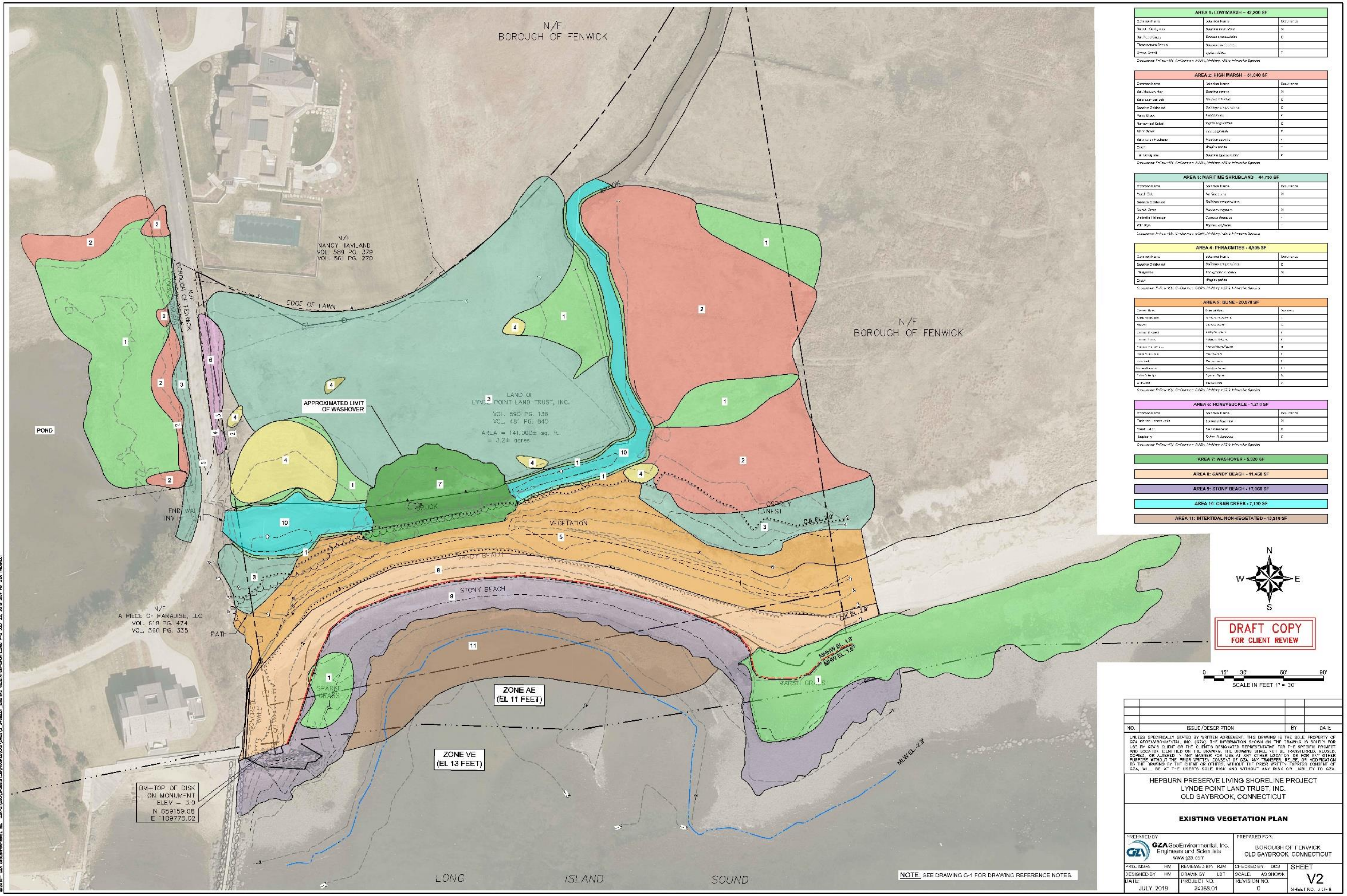
Marsh Sills
Marsh Creation




Overwash Material
Filling Crab Creek
Crab Creek
Existing Dune
Dune Breach
Winter 2019 Dune Breach (Looking East)

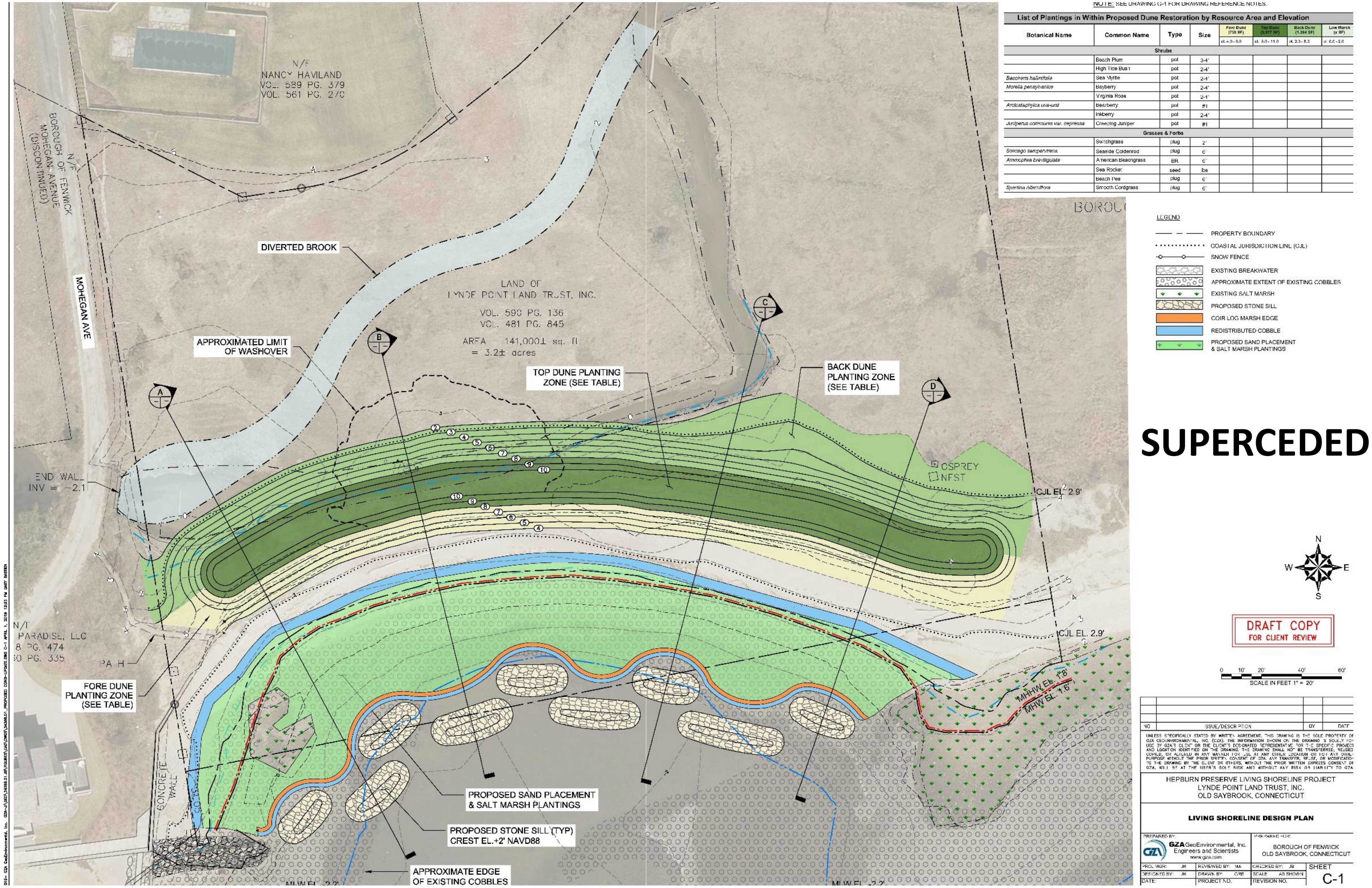
Winter 2019 Dune Breach (Looking West)

Temporary Fix



N/F
BOROUGH OF FENWICK
N/F
NANCY HAVLAND
VOL. 589 PG. 379
VOL. 561 PG. 270
EDGE OF LAWN
LAND OF
LYNDE POINT LAND TRUST, INC.
VOL. 590 PG. 136
VOL. 481 PG. 845
AREA = 141,000± sq. ft.
= 3.24 acres
APPROXIMATED LIMIT OF WASHOVER
POND
N/F
A PIECE OF PARADISE, LLC
VOL. 618 PG. 474
VOL. 560 PG. 335
PATH
VEGETATION
SANDY BEACH
STONY BEACH
SPARSE GRASS
MARSH GRASS
ZONE AE
(EL 11 FEET)
ZONE VE
(EL 13 FEET)
DM-TOP OF DISK
ON MONUMENT
ELEV = 3.0
N 659159.08
E 1189775.02
LONG ISLAND SOUND
NOTE: SEE DRAWING C-1 FOR DRAWING REFERENCE NOTES.
AREA 1: LOW MARSH – 42,200 SF
AREA 2: HIGH MARSH – 31,040 SF
AREA 3: MARITIME SHRUBLAND 44,750 SF
AREA 4: PHRAGMITES - 4,505 SF
AREA 5: DUNE - 20,970 SF
AREA 6: HONEYSUCKLE - 1,210 SF
AREA 7: WASHOVER - 5,920 SF
AREA 8: SANDY BEACH - 11,460 SF
AREA 9: STONY BEACH - 17,060 SF
AREA 10: CRAB CREEK - 7,150 SF
AREA 11: INTERTIDAL NON-VEGETATED - 13,510 SF
DRAFT COPY
FOR CLIENT REVIEW
0 15' 30' 60' 90'
SCALE IN FEET 1" = 30'
NO.
ISSUE/DESCRIPTION
BY
DATE
HEPBURN PRESERVE LIVING SHORELINE PROJECT
LYNDE POINT LAND TRUST, INC.
OLD SAYBROOK, CONNECTICUT
EXISTING VEGETATION PLAN
PREPARED BY
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com
PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT
PROJ. MGR: HM
REVIEWED BY: RJM
CHECKED BY: DCS
SHEET
DESIGNED BY HM
DRAWN BY LDT
SCALE: AS SHOWN
V2
DATE: JULY, 2019
PROJECT NO. 34368.01
REVISION NO. 0

Revised Alt. 5

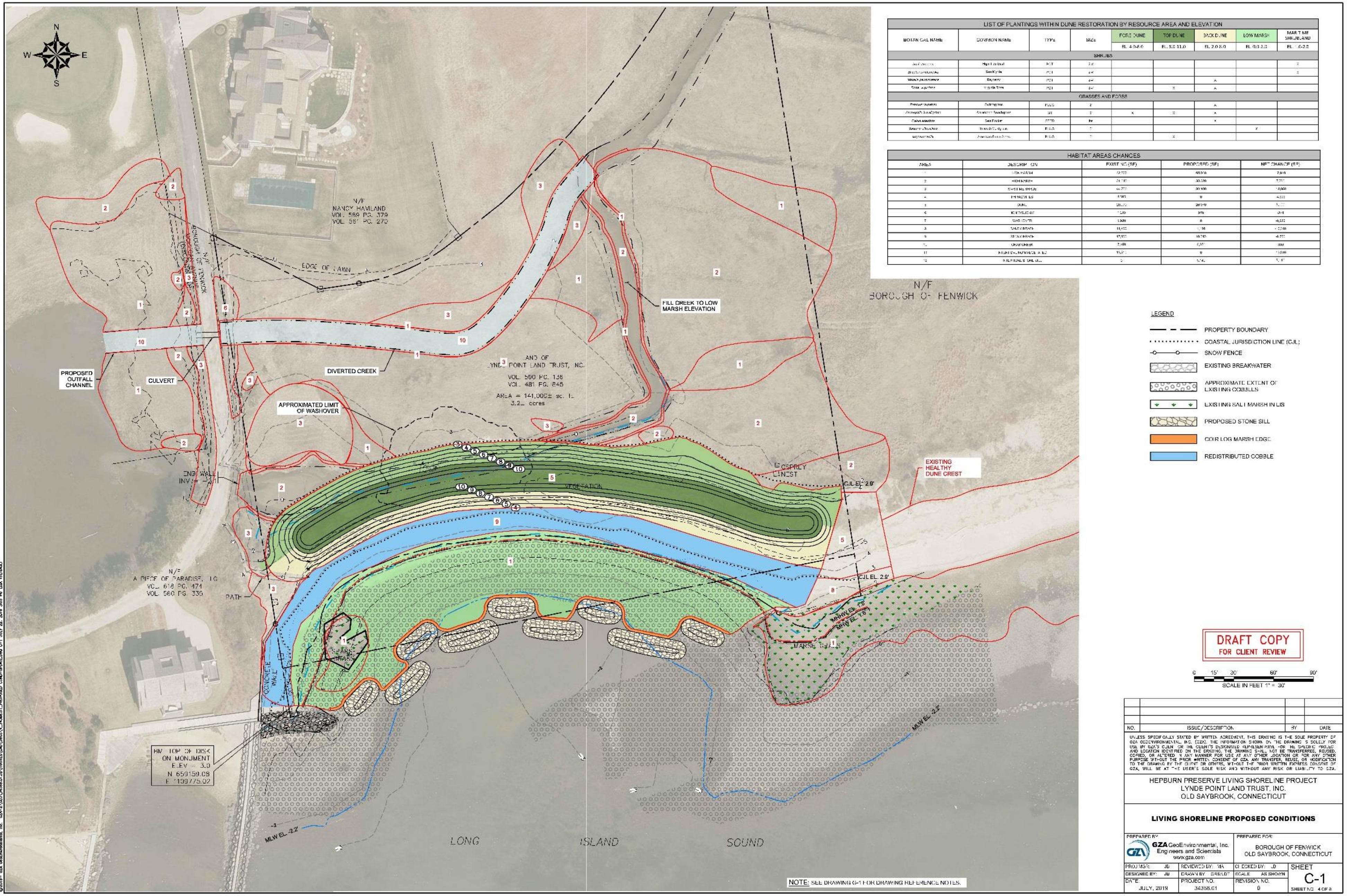


List of Plantings in Within Proposed Dune Restoration by Resource Area and Elevation

Botanical Name	Common Name	Type	Size	Fore Dune (738 SF) el. 4.0 - 8.0	Top Dune (2,977 SF) el. 8.0 - 11.0	Back Dune (1,394 SF) el. 2.0 - 8.0	Low Marsh (x SF) el. 0.0 - 2.0
Shrubs							
	Beach Plum	pot	3-4'				
	High Tide Bush	pot	2-4'				
Baccharis halimifolia	Sea Myrtle	pot	2-4'				
Morella pensylvanica	Bayberry	pot	2-4'				
	Virginia Rose	pot	2-4'				
Arctostaphylos uva-ursi	Bearberry	pot	#1				
	Inkberry	pot	2-4'				
Juniperus communis var. depressa	Creeping Juniper	pot	#1				
Grasses & Forbs							
	Switchgrass	plug	2"				
Solidago sempervirens	Seaside Goldenrod	plug	6"				
Ammophila breviligulata	American Beachgrass	BR	6"				
	Sea Rocket	seed	lbs				
	Beach Pea	plug	6"				
Spartina Alterniflora	Smooth Cordgrass	plug	6"				

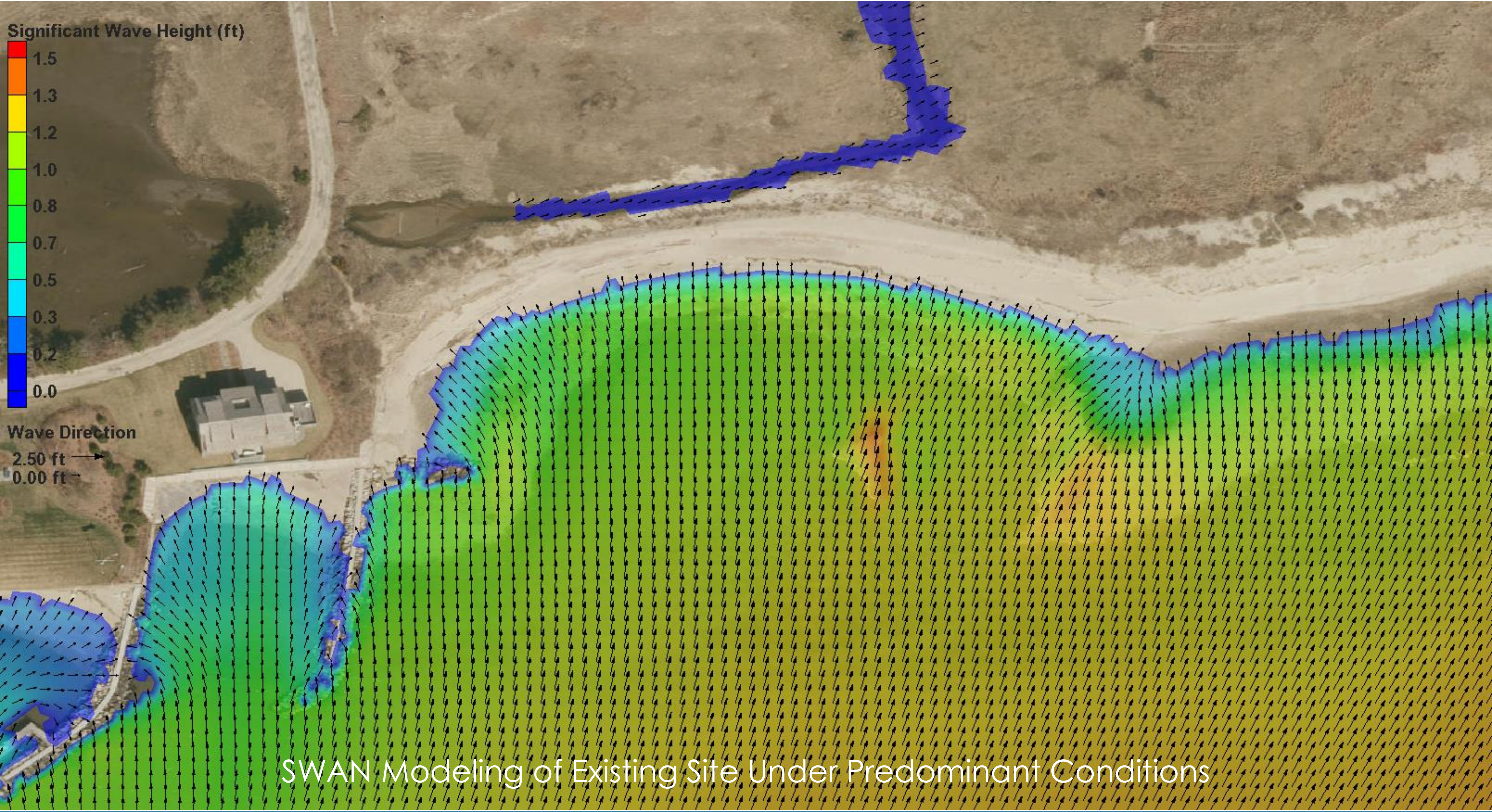
SUPERCEDED

Alt. 6

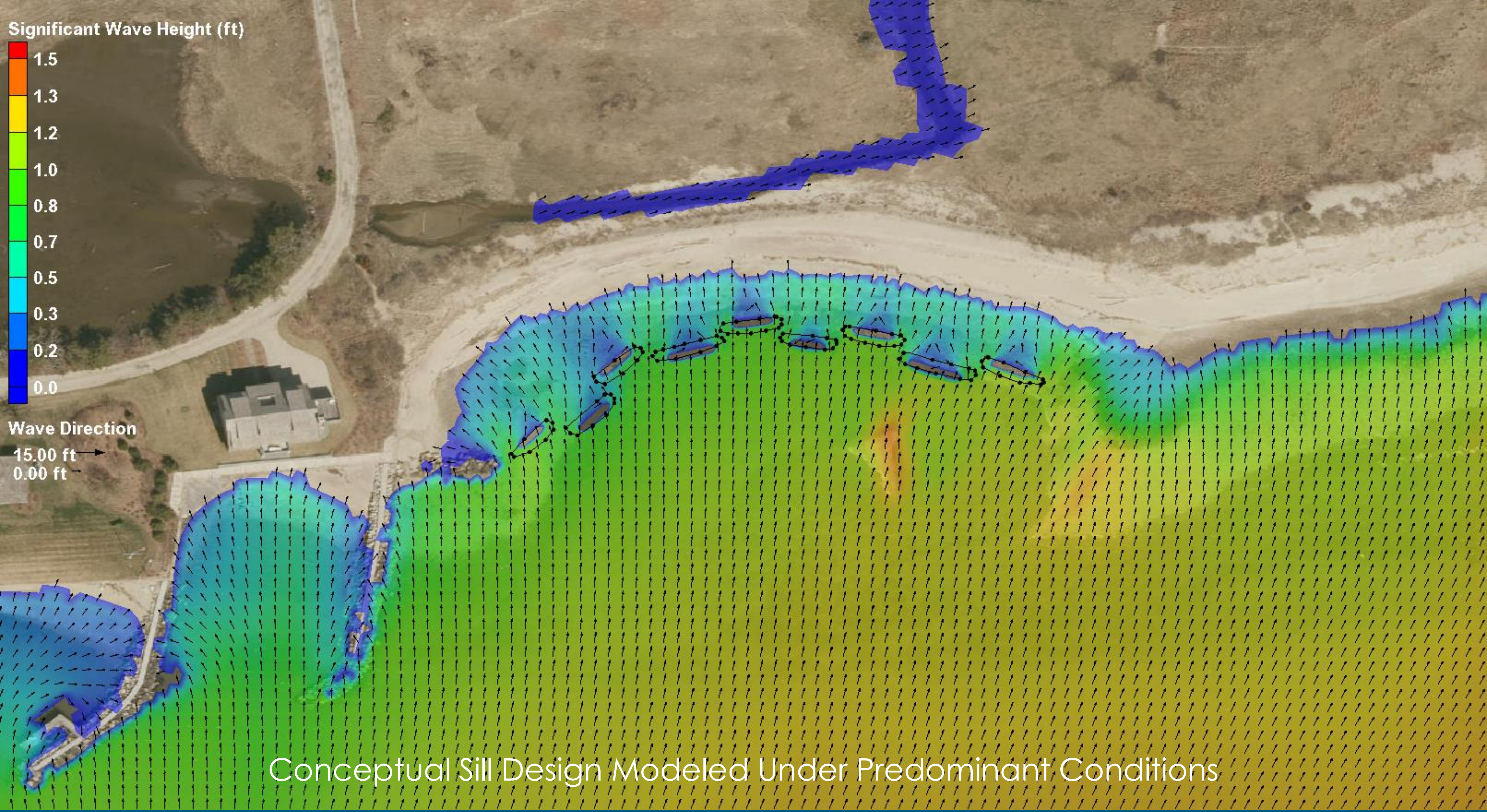

LIST OF PLANTINGS WITHIN DUNE RESTORATION BY RESOURCE AREA AND ELEVATION
HABITAT AREAS CHANGES
N/F NANCY HAVILAND VOL. 589 PG. 379 VOL. 581 PG. 270
EDGE OF LAWN
N/F BOROUGH OF FENWICK
FILL CREEK TO LOW MARSH ELEVATION
DIVERTED CREEK
PROPOSED OUTFALL CHANNEL
CULVERT
LAND OF LYNDE POINT LAND TRUST, INC.
VOL. 590 PG. 158
VOL. 481 PG. 846
AREA = 141,006± sq. ft.
3.2± acres
APPROXIMATED LIMIT OF WASHOVER
EXISTING HEALTHY DUNE CREST
OSPREY NEST
CJL EL. 2.9'
VEGETATION
N/F A PIECE OF PARADISE, LLC VOL. 618 PG. 471 VOL. 560 PG. 335
PATH
CONCRETE WALL
MLW EL. -2.2'
HM TOP OF DISK ON MONUMENT ELEV = 3.0 N 659159.08 E 1109775.02
LONG ISLAND SOUND
NOTE: SEE DRAWING G-1 FOR DRAWING REFERENCE NOTES.
LEGEND
PROPERTY BOUNDARY
COASTAL JURISDICTION LINE (CJL)
SNOW FENCE
EXISTING BREAKWATER
APPROXIMATE EXTENT OF EXISTING COBBLES
EXISTING SALT MARSH IN LIS
PROPOSED STONE SILL
COIR LOG MARSH EDGE
REDISTRIBUTED COBBLE
DRAFT COPY FOR CLIENT REVIEW
SCALE IN FEET 1" = 30'
HEPBURN PRESERVE LIVING SHORELINE PROJECT
LYNDE POINT LAND TRUST, INC.
OLD SAYBROOK, CONNECTICUT
LIVING SHORELINE PROPOSED CONDITIONS
GZA GeoEnvironmental, Inc. Engineers and Scientists www.gza.com
BOROUGH OF FENWICK OLD SAYBROOK, CONNECTICUT
JULY, 2019
34358.01
C-1

Alt. 6

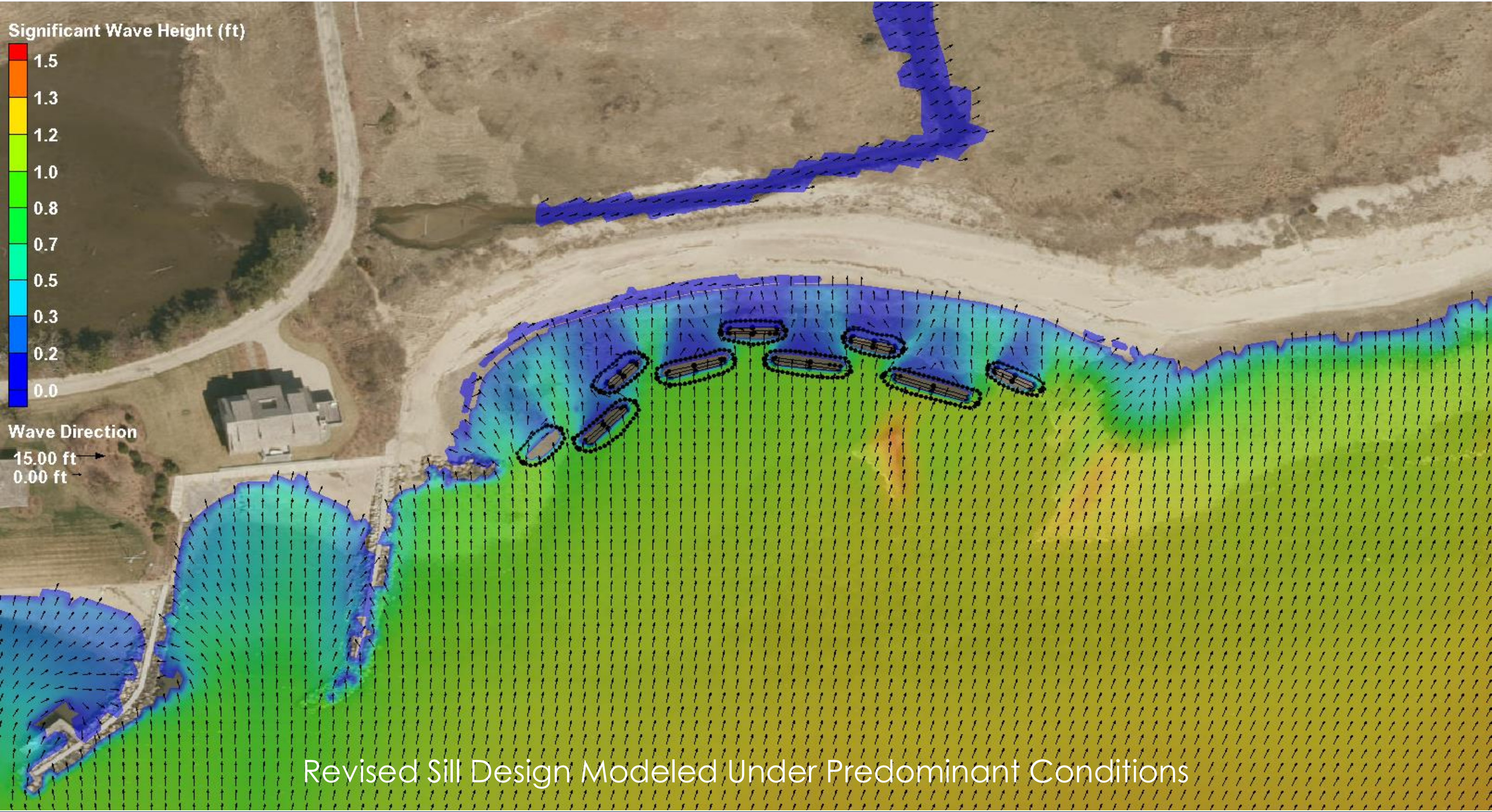
HABITAT AREA CHANGES				
AREA	DESCRIPTION	EXISTING (SF)	PROPOSED (SF)	NET CHANGE
1	LOW MARSH	42,200	60,040	17,840
2	HIGH MARSH	31,040	38,320	7,280
3	MARITIME SHRUB	44,750	30,100	-14,650
4	PHRAGMITES	4,505	0	-4,505
5	DUNE	20,970	26,070	5,100
6	HONEYSUCKLE	1,210	970	-240
7	WASHOVER	5,920	0	-5,920
8	SANDY BEACH	11,460	1,150	-10,310
9	STONY BEACH	17,060	10,310	-6,750
10	CRAB CREEK	7,150	6,820	-330
11	INTERTIDAL NON-VEGETATED	13,510	0	-13,510
12	INTERTIDAL STONE SILL	0	5,140	5,140



SWAN Modeling of Existing Site Under Predominant Conditions



Conceptual Sill Design Modeled Under Predominant Conditions


Significant Wave Height (ft)
1.5
1.3
1.2
1.0
0.8
0.7
0.5
0.3
0.2
0.0
Wave Direction
15.00 ft
0.00 ft
Revised Sill Design Modeled Under Predominant Conditions

Existing Conditions

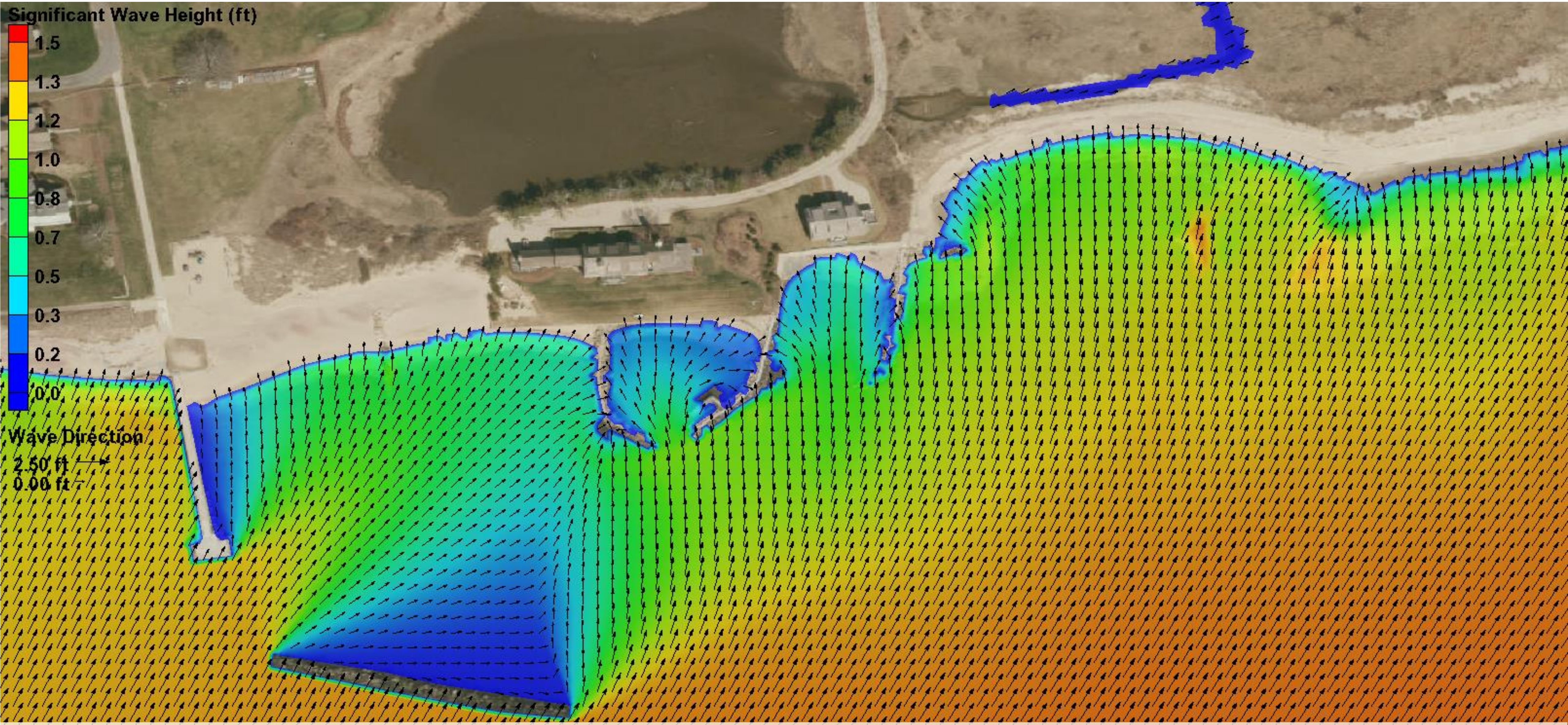
Conceptual Living Shoreline Design

Questions?

GZA

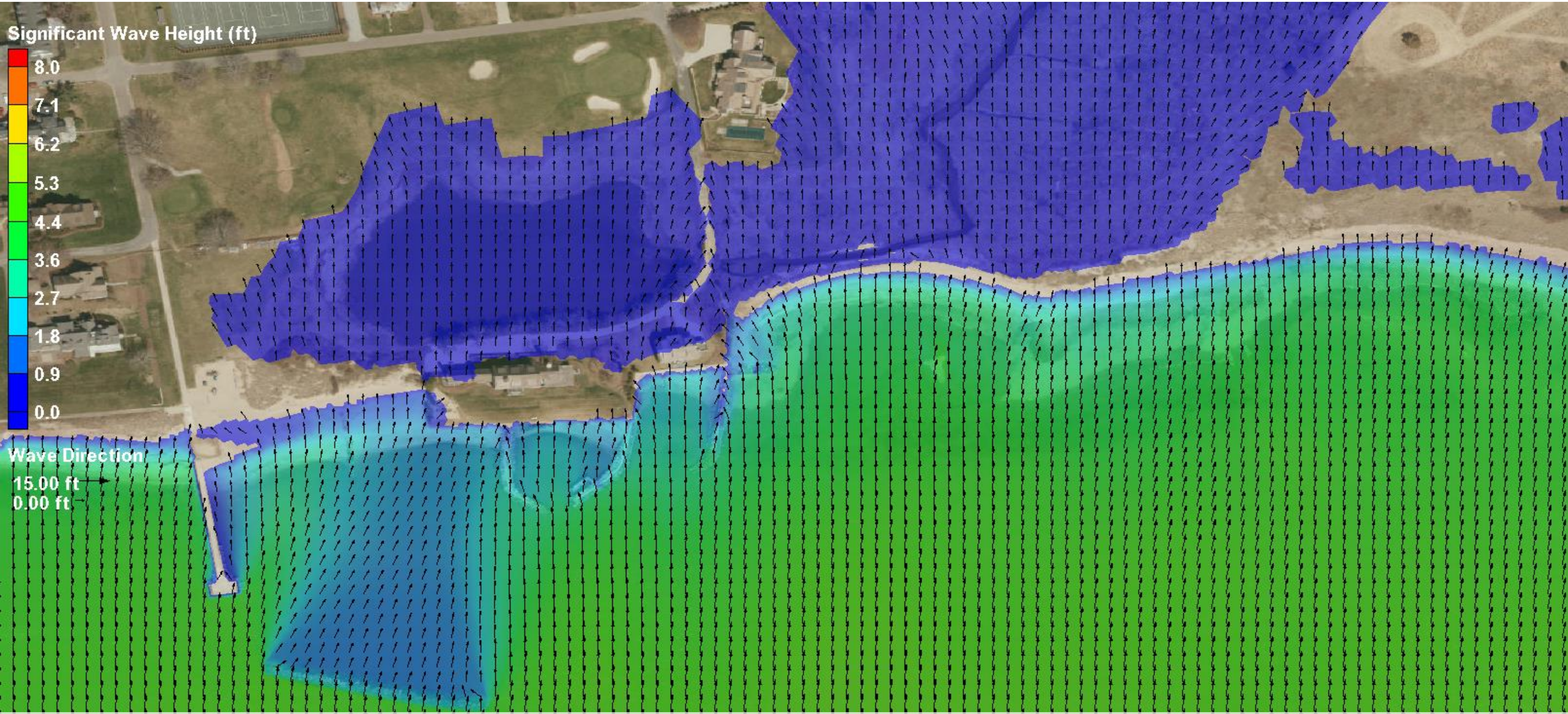
Hande McCaw | Stephen Lecco

Numerical Modeling: Predominant Conditions



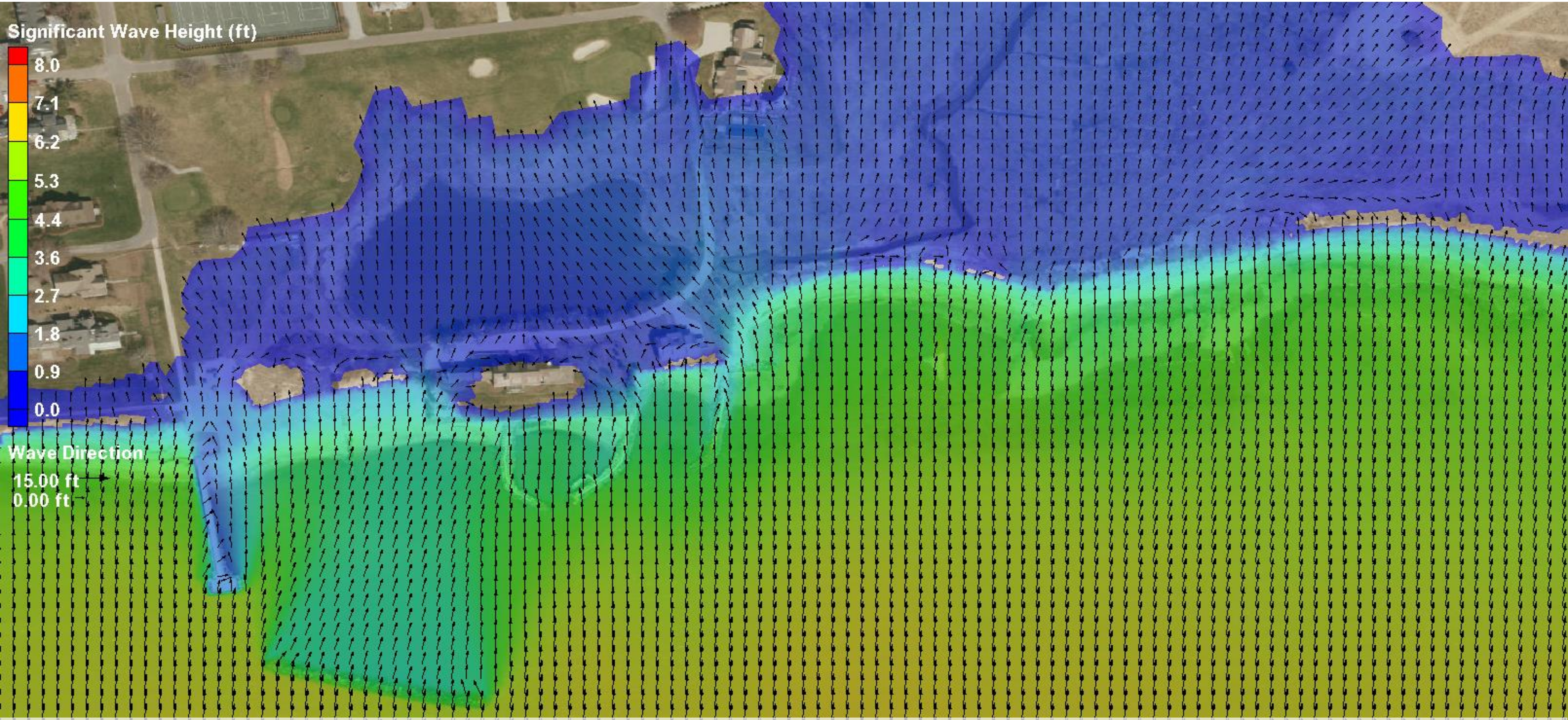
Model Input: Wind Speed 16 mph | Wind Direction WSW | Water Level 1.5ft NAVD88 (MHW) | Wave Height 2.5ft | Wave Direction WSW

Numerical Modeling: 2-Yr Storm (50% Annual Probability)



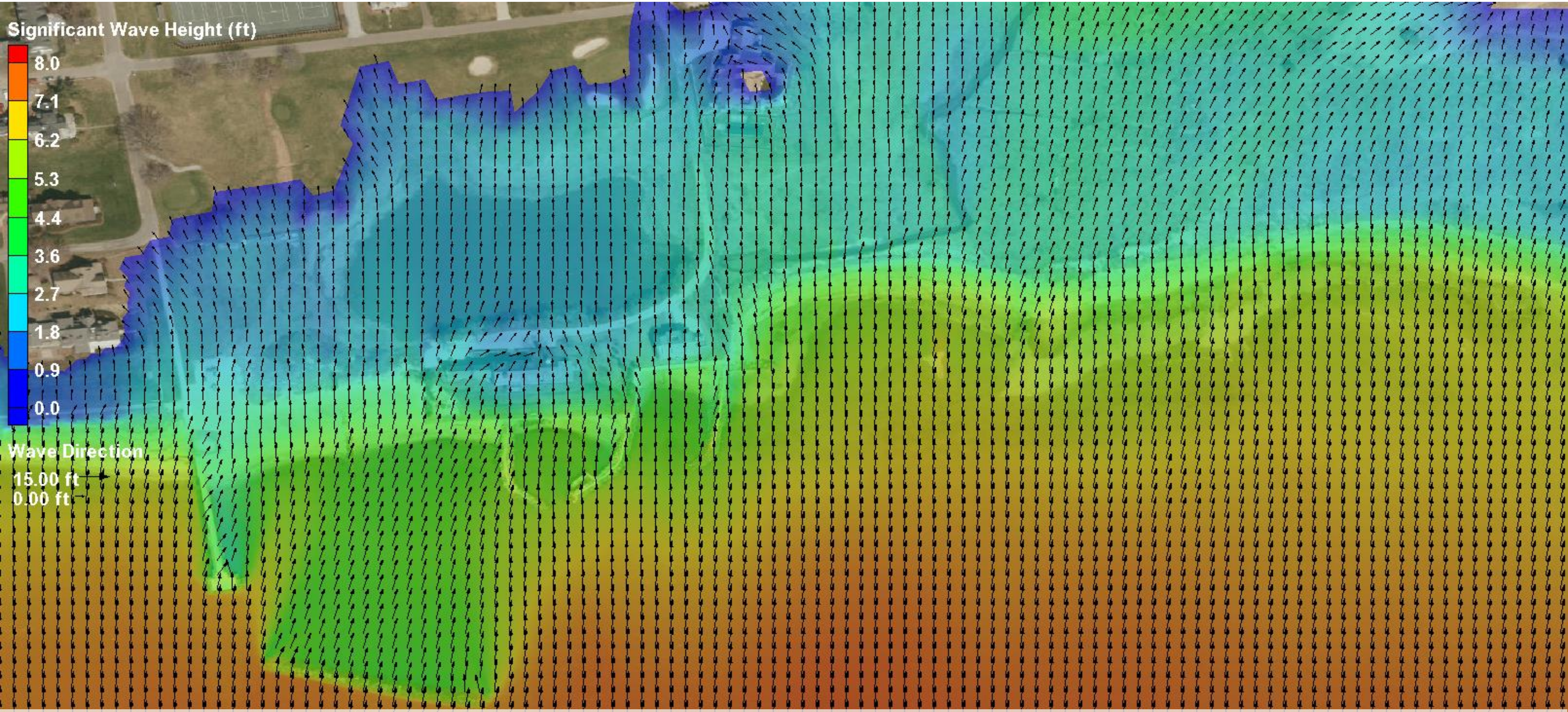
Model Input: Wind Speed 35 mph | Wind Direction S | Water Level 4.8ft NAVD88 | Wave Height 8.3ft | Wave Direction S

Numerical Modeling: 10-Yr Storm (10% Annual Probability)



Model Input: Wind Speed 56 mph | Wind Direction S | Water Level 6.7ft NAVD88 | Wave Height 10.4ft | Wave Direction S

Numerical Modeling: 100-Yr Storm (1% Annual Probability)



Model Input: Wind Speed 72 mph | Wind Direction S | Water Level 9.4ft NAVD88 | Wave Height 11.9ft | Wave Direction S

Appendix I – GZA Alternatives Analysis Report

Proactive by Design

DRAFT
HEPBURN PRESERVE LIVING SHORELINE PROJECT
SHORELINE STABILIZATION ALTERNATIVES ANALYSIS

BOROUGH OF FENWICK

Old Saybrook, Connecticut

Revised August 30, 2019
File No. 03.0034368.02

PREPARED FOR:

Borough of Fenwick
Old Saybrook, Connecticut

GZA GeoEnvironmental, Inc.
530 Broadway | Providence, RI 02909
401-421-4140

26 Offices Nationwide
www.gza.com

Proactive by Design

GEOTECHNICAL
ENVIRONMENTAL
ECOLOGICAL
WATER
CONSTRUCTION MANAGEMENT

530 Broadway
Providence, RI 02909
T: 401.421.4140
F: 401.751.8613
www.gza.com

Via Electronic Delivery

August 30, 2019
File No. 03.0034368.02

Ms. Marilyn Ozols
Borough of Fenwick
580 Maple Avenue, P.O. Box 126
Old Saybrook, CT 06471-3001

Re: DRAFT SHORELINE STABILIZATION ALTERNATIVES ANALYSIS
Hepburn Preserve Living Shoreline Project
Borough of Fenwick, Old Saybrook, CT

Dear Ms. Ozols:

GZA GeoEnvironmental, Inc. (GZA) is pleased to present our report presenting shoreline stabilization alternatives for the Hepburn Preserve in the Borough of Fenwick, Old Saybrook Connecticut. This analysis of alternatives is required for permit applications that will be submitted for this project. A draft of this report was submitted to you previously on March 2, 2019 report. A change to this earlier draft is the addition of alternatives that address breaching of the dune on the site such as occurred during the winter of 2019.

Chronic and episodic erosive shoreline change has been an on-going issue along the approximately 450 linear foot barrier spit that makes up the Hepburn Dune section of Long Island Sound shoreline. The Borough has expended significant effort and cost to restore the tidal marsh and stabilize the shoreline and during the last 10 to 15 years. Shoreline erosion, however, continues. The proximity of the eroded shoreline, which is now close to the tidal marsh and Crab Creek, increases the likelihood that the remaining sand spit will be breached during future coastal storms. Unrepaired breach of the barrier spit could have negative consequences for both improved property in the area and the restored tidal marsh and creek located inland of the barrier spit. Future breaches will also require periodic maintenance to excavate overwash sand from Crab Creek and associated costs.

The goal of the project is to stabilize the long-term shoreline erosion through the use of a Living Shoreline, consistent with current State guidance. GZA assisted the Borough with a successful grant application with the Connecticut Institute for Resilience & Climate Adaptation (CIRCA) and the Long Island Sound Futures Fund (LISFF) to assist with funding for final engineering and design, permitting and construction. As part of these grants, the project will be used as a case study for constructing a Living Shoreline in Connecticut.

This report presents several conceptual alternatives for shoreline stabilization. Each of these alternatives has components of a Living Shoreline as defined by the State of Connecticut. The alternatives vary in cost, project extent, use of hard structures and degree of protection provided. Specifically, we note that the project site is vulnerable to significant wave action and storm surge during coastal flood events which makes it a high energy environment for a typical Living Shoreline. The different alternatives have different performance expectations and, therefore, certain alternatives will have greater maintenance costs than others.

The development of the Living Shoreline design, including evaluation of the different alternatives, included: 1) an analysis of metocean (wind, wave and water level) conditions applicable to the site; 2) numerical hydrodynamic modeling of tide and storm surge; 3) numerical and analytical modeling of waves; 4) evaluation of new marsh survivability; 5) numerical modeling of tidal circulation within the Lynde Point Marsh; 6) conceptual design of different alternatives; and 7) a comparative analysis of the alternatives.

We appreciate the opportunity to assist you with this project. Please call the undersigned with questions. GZA will also present our results and recommendations in person to the Borough once this report is complete.

Very truly yours,
GZA GEOENVIRONMENTAL, INC.

Hande McCaw, P.E.[FL, MA]
Senior Project Manager/Coastal Engineer

Stephen Lecco
Consultant/Reviewer

Daniel C. Stapleton, P.E.
Senior Principal

Attachments: Appendix A: Limitations
Appendix B: Photographs of Existing Conditions
Appendix C: Shoreline Change Analysis
Appendix D: Summary of Previous Dune Reconstruction, Observed Post-Storm Conditions
Appendix E: Results of Wind and Wave Analysis
Appendix F: Numerical Model Simulation Results
Appendix G: Alternative 5 Numerical Model Simulation Results
Appendix H: COP Letter from DEEP
Appendix I: Existing Conditions and Alternatives Concept Plans

INTRODUCTION

GZA GeoEnvironmental, Inc. (GZA) was retained by the Borough of Fenwick in Old Saybrook, CT to develop shoreline stabilization alternatives for the approximately 450 linear foot barrier spit that makes up the Hepburn Preserve Dune section of shoreline (see **Figure 1**, below). The project site is located on the southern shoreline of Fenwick (on Long Island Sound), adjacent to (to the east of) the former Katherine Hepburn Estate. The site is currently owned by the Lynde Point Land trust.

Figure 1: Project Site Location

Chronic and episodic shoreline erosion have been on-going issues along this small barrier spit. Review of historic photographs and shoreline change data indicates that the shoreline erosion is due, in part, to the construction of coastal structures including groins and breakwaters, within sand transport updrift locations. The Borough has expended significant effort and cost to restore the Lynde Point Marsh and stabilize the beach dune during the last 10 to 15 years; however, shoreline erosion continues. Due to the proximity of the eroded shore to the tidal marsh and Crab Creek, there is a significant risk of breach of the dune and beach during coastal flood events such as occurred during the winter of 2019. The 2019 breach resulted in sand overwash within the Crab Creek and flooding of the marsh with ocean waters. In response, the Connecticut Department of Energy and Environmental Protection (DEEP) excavated the overwash sand from the tidal creek and placed a temporary culvert to maintain creek flow. Unrepaired future breaches could have negative consequences for both improved property in the area and the recently restored Lynde Point Marsh, and result in periodic maintenance and repair costs.

This report presents several conceptual alternatives for shoreline stabilization. Each of these alternatives has components of a Living Shoreline as defined by the State of Connecticut. The alternatives vary in cost, project extent, use of hard structures and degree of protection provided. This report is subject to the Limitations presented in **Appendix A**.

BACKGROUND

During 2004 to 2006, the Lynde Point Marsh (located inland of the project site) was restored by the Borough in partnership with the Connecticut DEEP Wetlands Restoration Unit and other partners. The project restored 10 acres of tidal wetland through the removal of 60,000 cubic yards of dredge sediment placed within the former tidal marsh during the 1940's which converted the tidal wetlands to non-tidal uplands and were subsequently inundated with phragmites. Removal of dredge sediment as a part of the marsh restoration project returned the area to tidal wetlands, open water, panne and brackish meadow habitats that are beneficial to migratory waterfowl, wading birds, shorebirds and nesting passerines. The marsh restoration project improved habitat for federally endangered shortnose sturgeon and the state threatened Atlantic sturgeon. Other species to benefit from this project included the bald eagle, northern harrier, northern diamondback terrapin, seaside and saltmarsh sharp-tailed sparrow, and wilet and glossy ibis.

The barrier spit separating the marsh and tidal creek has been experiencing long-term shoreline erosion and the width of the spit is narrow and vulnerable to breach during a coastal storm event. Review of historic photographs and shoreline change data indicates that the shoreline erosion is due, in part, to the construction of coastal structures, including groins and breakwaters, within sand updrift locations. A breach would have negative consequences for both improved property in the area and the recently restored tidal marsh and creek located inland of the barrier spit. A breach in the barrier spit would potentially result in: 1) creation of a tidal inlet, open to Long Island Sound; 2) erosion of the tidal marsh and creek; 3) change in the salinity of the marsh, resulting in ecological impact; and 4) damage to improved property including the existing drainage culvert (under Mohegan Avenue), the roadway, and both developed and undeveloped property (Hepburn Estate). A permanent breach of the barrier spit would result in significant change to the nature of the southern shoreline of Fenwick.

In an attempt to stabilize the barrier spit and dune, a reinforced dune was constructed in 2007 using Filtrex sand-filled tubes and imported sand. The reinforced dune was planted in 2008 with American beach grass and switch grass, which became well-established. However, Hurricane Irene and subsequently Superstorm Sandy completely eroded the reinforced dune, destroyed the sand tubes and deposited overwash sand in the backwater marsh and creek.

During April of 2017, The Borough contacted Mr. Peter Francis, the Supervising Environmental Analyst in the Coastal Resources Section of the Land & Water Resources Division of the Connecticut DEEP, who suggested a Living Shoreline approach to dune and marsh protection. The Living Shoreline approach suggested by Mr. Francis included dune restoration, beach sand placement, coir logs, new marsh, stone sills and wave attenuation structures.

The Borough contracted with GZA to: 1) evaluate the existing conditions at the site; and 2) develop shoreline stabilization alternatives (preferably using a Living Shoreline approach). During 2017, GZA assisted the Borough with a successful grant application with the Connecticut Institute for Resilience & Climate Adaptation (CIRCA) to assist with funding for final engineering and design. As part of the grant, the project, if undertaken, will be used as a case study for constructing a Living Shoreline in Connecticut.

During the winter of 2019, storm activity led to a breach in the dune with overwash material filling the adjacent Crab Creek as illustrated in **Figure 2** below. With the tidal creek filled, the adjacent salt pond west of Mohegan Avenue has been slow to drain following rain events leading to increased water elevations in the pond. The Borough of Fenwick worked with DEEP's Wetland Restoration Unit to respond to this situation. The emergency response plan included: 1) excavating the overwash material from the creek and depositing recovered material within the original dune footprint; 2) installing a temporary 36-inch diameter corrugated pipe within the section of the creek previously filled to maintain tidal connection in case of future breaches; and 3) anchoring drift trees within the footprint of the dune breach to provide some protection from future storm activity. This response was considered to be a temporary measure.

PURPOSE

The purpose of GZA's engineering analysis and design was to develop several shoreline stabilization alternatives, ideally (to the extent practical for the site conditions) using a Living Shoreline approach as defined by the State of Connecticut. Living Shorelines are nature-based erosion control techniques, relatively new to Connecticut and an alternative to hard coastal structures (e.g., breakwaters, revetments). Per CIRCA… "Living shorelines mimic natural settings and have many positive co-benefits to erosion control, including but not limited to: habitat creation, water quality enhancement, and maintaining natural coastal processes." Relocation of a portion of Crab Creek is also proposed (Alternative 6) to provide for construction of an enhanced dune and to maintain tidal flow within the marsh and pond.

Figure 2: Winter 2019 Dune Breach and Overwash Impacting Crab Creek

The performance objectives of the shoreline stabilization alternatives are to: 1) mitigate the on-going, chronic shoreline erosion; 2) restore the dune; 3) reduce the probability of a breach of the barrier spit; 4) maintain the Lynde Point Marsh tidal flow; 5) enhance the existing habitat; 6) maintain the natural aesthetic; 7) reduce additional, significant disruption of the natural coastal processes; and 8) provide a range of costs, permitting timelines and levels of protection to consider.

The site location, along the southern shoreline of Fenwick, is directly exposed to Long Island Sound including tides; storm surge; waves during normal, prevailing conditions and coastal storms; and cross-shore and longshore sediment transport. As such, the shoreline stabilization alternatives are required to be relatively robust (due to the high wave energy) to achieve the performance objectives presented above. The construction cost, maintenance and repair costs and physical performance differs between the alternatives, including a No Action alternative.

As described below and in the Appendices, the specific site challenges include: 1) coastal storm surge and waves which directly cause dune erosion and potentially breach; and 2) creating the elevation and wave environment conducive to marsh survivability. Long-term, chronic shoreline change enhances these challenges as will future sea level rise. An additional consideration is the presence of coastal structures which reduce the sand that is naturally available to the site; dune and beach maintenance will require imported sand.

GZA has performed detailed metocean data and numerical storm surge and wave modeling to define the existing environmental conditions in terms of probability. GZA has also performed numerical wave modeling and circulation modeling of the Lynde Point Marsh to evaluate future performance. GZA has reviewed and utilized Living Shoreline design guidance that was established for other regions (in particular, the Chesapeake Bay area, Delaware and North Carolina) and adapted this guidance to the more robust wave environment of Long Island Sound. In particular, technical guidance was applied to establish: 1) the appropriate elevation and tidal conditions for new marsh establishment; 2) the prevailing wave conditions necessary for new marsh establishment and maintenance; 3) wave attenuation during storm events to reduce the likelihood of uprooting and stem breakage; and 4) a site environment that would support the reestablishment of the Living Shoreline marsh should it become damaged during a storm.

Due to the robust Long Island Sound wave environment and the site vulnerability during coastal storms, there is a temptation to employ coastal structures such as breakwaters (rather than typical wetland sills) and stone core-reinforced dunes to minimize storm damage and loss of construction investment – in particular due to high frequency coastal flood events. The shoreline protection alternatives presented here attempt to fall within the Connecticut Living Shoreline expectations, at some risk of future damage. The sill geometry, including crest elevation, was selected to provide wave attenuation during prevailing conditions (for marsh establishment) and some level of wave attenuation during coastal storm events. However, to be consistent with the intent of a Living Shoreline the design is not as robust as a standard offshore breakwater; and therefore will have some performance limitations during storm events. Preliminary regulatory feedback indicated that a less robust sill (than initially designed) is desirable.

The configuration of the Living Shoreline alternatives was selected: 1) to provide at least a minimal width of Living Shoreline marsh; and 2) reduce the risk of creating future erosion issues to the east of the project site by constructing sills that are further seaward than shown here and modifying wave refraction. Also, staggered sills have been utilized.

Certain shoreline alternatives include a stone core-reinforced dune. This is due to the very narrow space available for dune construction and restoration. While accepted in other states, we recognize based on preliminary regulatory feedback that this is not desirable. Other alternatives were developed that allow partial relocation of Crab Creek in order to create space for construction of a higher, wider dune. These alternatives propose dune geometries that are consistent with areas located immediately east of the site and are sustainable once shoreline change is mitigated.

EXISTING CONDITIONS

Photographs of the existing conditions at the site are presented in **Appendix B**. The existing site conditions are also presented in the **Existing Conditions Plan**, including pre and post dune breach conditions that occurred in 2019.

The project shoreline consists of an eroding small barrier spit including: 1) a low, narrow, eroded dune; 2) a cobble to sandy beach (transitioning to a sandy beach to the east); 3) a cobble intertidal zone with several boulders; and 4) two small, isolated patches of marsh vegetation at the western and eastern edges of the site (founded on a very thin sand layer over cobbles).

The barrier beach separates Long Island Sound from Lynde Point Marsh and the tidal Crab Creek. Storm overwash sand deposits are present in the existing marsh.

Several granite stone breakwaters and groins are present in the site vicinity, including an east-west trending knee breakwater located at the southwest portion of the site. A masonry wall is present to the north of the knee breakwater, separating the beach from developed land.

The barrier spit has eroded to a cuspate configuration. The eastern portion of the site is characterized by a shallow, gravel “peninsula”. There is a low, natural or manmade line of boulders east of the project site in the nearshore (**Appendix B Figure 7**). This line of boulders is acting to some degree as a sill, which is contributing to the growth of marsh vegetation

in this area. The submerged area between this “peninsula” and the knee breakwater is deeper due to lack of alongshore sediment supply and erosion, reflecting slightly higher tidal and wave current velocities.

The elevation of the dune at the project site (as of the survey date of April, 2017) is low at about Elevation +5 feet NAVD88. As of February, 2019 ground elevations in the vicinity of the dune breach were at approximately +4 feet NAVD88. The width of the dune (at the base) is approximately 20 feet where it remains intact. The dune is generally located outside of the Coastal Jurisdiction Line (CJL) which lies at Elevation 2.9 feet NAVD88 in Old Saybrook. The width of the barrier spit separating Long Island Sound from the marsh (at its thinnest, measured Mean High Water to Mean High Water) is about 50 feet.

The dune system located approximately 600 feet to the east of the project site is in a healthier condition with higher crest elevations (**Figure 3**), wider base and with established beach grass. Dune crest elevations range between Elevations 7.0 to 13.3 feet- NAVD and the dune width at the base ranges from about 35 to 60 feet. This dune system is used as a reference area during the design of the proposed dune.

Figure 3: Reference Dune Area to the East of the Project Site

SHORELINE CHANGE

Appendix C presents historical aerial photographs and calculated shoreline change rates for the project site and vicinity. These were developed by the University of Connecticut (UCONN) Center for Land Use Education and Research (CLEAR). The shoreline change rates were calculated for two periods: 1) long-term shoreline change, reflecting the period from the 1880’s to 2006; and 2) short-term shoreline change, reflecting the period from the 1983 to 2006.

Shoreline change along the southern shore of Fenwick, including the project site, is due to: 1) the availability and longshore transport of sand (littoral drift); and 2) cross-shore sediment transport that occurs seasonally and during coastal storms. Each of these shoreline change components work together to result in a net shoreline change.

Short-term shoreline change:

As indicated on presented in **Appendix C, Figure 1** the short-term (1983 to 2006) shoreline change at the project site has been negative (i.e., net erosion) at an average change rate of about 0.6 meters/year (2.0 feet per year). The exception is at the westernmost portion of the site, where the knee breakwater refracts and attenuates waves resulting in localized accretion.

Beach accretion is occurring within the area located immediately east of the site at a change rate of about 0.5 meters/year (1.6 feet/year), coinciding with the low boulder sill and cobble "peninsula". As discussed later in this report, GZA's wave modeling indicates that this area of accretion falls just outside the influence of the offshore breakwater located southwest of the project site.

Long-term shoreline change:

There has been significant long term, negative shoreline change (erosion) at the project site on the order of 0.5 meters/year (1.6 feet/year) from 1880 to 2006 (as indicated on Figure 2 presented in **Appendix C)**. This shoreline change has occurred principally as a result of the disruption of longshore sediment transport due to the construction of coastal structures, in particular the network of offshore breakwaters, groins and breakwaters constructed to the west of the project site. The net longshore sediment transport in the vicinity of the project site is to the east. These structures to the west of the project site were constructed to locally attenuate wave energy at the adjacent properties and to encourage accretion of sand (within the localized influence zones of the structures). However, their effect has also been to reduce the availability of sand to the project site. As indicated on the photographs and plans presented in **Appendix C**, the original, natural shoreline was present at the project site during 1880. Noticeable changes in shoreline orientation at the project site occurred subsequent to construction of the coastal structures (beginning sometime between 1880 and 1934).

PREVIOUS SHORELINE STABILIZATION CONSTRUCTION

Appendix D presents photographs of the previous shoreline stabilization efforts, storm conditions at the site (Hurricane Irene and Superstorm Sandy), and the post-storm site conditions.

The dune was reconstructed in 2007 in an attempt to stabilize the barrier beach. The dune was reconstructed and reinforced using Filtrex sand-filled tubes and imported sand. The reconstructed, reinforced dune was planted in 2008 with American beach grass and switch grass, which became well-established in following years.

Hurricane Irene (2011) and subsequently Superstorm Sandy (2012) completely eroded the reinforced dune, destroyed the sand tubes and deposited overwash sand in the backwater marsh and creek. As indicated in photos taken during Hurricane Irene), the storm conditions included elevated storm tides and waves. The stillwater elevations (storm tide elevation, excluding wave effects) observed at Old Saybrook during Hurricanes Irene and Sandy were about Elevations +6 and +8 feet NAVD88, respectively. These water levels are 0 to 3 feet above the current dune crest elevation. Coincident significant wave heights were on the order of about 3 to 6 feet. Based on the observed water levels and wave, these storms represented conditions with an annual exceedance probability of about 20% to 10% (aka 5-year to 10-year recurrence intervals). This means that the conditions observed during these storms are predicted to have a 10% to 20% chance, today, of being equaled or exceeded in any given year. Sea level rise will increase the occurrence probability of these storms in the future.

ENVIRONMENTAL SITE CONDITIONS

GZA completed a detailed analysis of available metocean data applicable to Old Saybrook, including the project site. The results of the metocean data analysis are presented in the publically-available "Old Saybrook Coastal Resilience Study" (this study was funded by a HUD Community Development Block Grant).

The results of the metocean data analysis were used to define the:

1. The prevailing wind and wave conditions. These are the conditions that are typically present in the absence of storms;
2. The tides and tidal datums;
3. Sea level rise projections; and
4. Extreme water levels and waves associated with coastal storms, defined by probability (annual exceedance probabilities).

The results of the metocean data analysis were used to develop input to:

1. Statistical analysis of prevailing wind and associated wave heights at the project site (results presented in **Appendix E**);
2. Numerical modeling (results presented in **Appendix F**) of water level and waves at the project site for:
    a. Prevailing conditions; and
    b. Storms with annual recurrence intervals of 2, 10 and 100-year return periods.

The prevailing wind and wave conditions, along with tide data, are used to evaluate the suitability of the existing conditions at the site for the development of new Living Shoreline tidal marsh. Research conducted by Shafer (Shafer et al, 2003) identified a threshold wave height for marsh survivability and successful growth. This study estimated through empirical field data that salt marshes do not survive in wave climates with representative wave heights exceeding about 0.14 meter (0.5 foot). Other studies indicate similar results[1]. Representative wave heights are defined in the study as the maximum significant wave height associated with the waves that occur 80 percent of the time; that is, have an exceedance probability of 20% ($H_{20\%}$). The statistical hindcast analysis, and simple wave model, presented in **Appendix E** indicate that at the project site the $H_{20\%}$ is about 0.3 meter (about 0.9 foot). This value exceeds the empirical wave height survivability criteria, indicating that wave attenuation will be required to establish marsh vegetation (i.e., use of wave attenuation structures such as sills or breakwaters will be required to create a calmer wave energy environment if marsh enhancement is to be included in the proposed shoreline stabilization).

The existing isolated areas of marsh vegetation are at locations where GZA's numerical wave modeling of prevailing wave conditions (see **Appendix F**) predicts wave heights $\leq$ 0.5 foot. This finding appears to support the established empirical criteria presented above.

The proposed development of new marsh will constitute low marsh planted in areas corresponding to the intertidal zone, approximately between Mean Sea Level (MSL) and Mean High Water (MHW). The tidal datums at Old Saybrook are presented in **Table 1** for current conditions and conditions associated with projected sea level rise (USACE High Projection, which are generally consistent with the updated NOAA 2017 projections and the Connecticut established projections) for the years 2040, 2070 and 2100.

[1] It is noted, however, that these studies were conducted principally in the mid-Atlantic and Chesapeake Bay Regions and may not be directly applicable to Long Island Sound. Regardless, they provide a valuable baseline for developing Living Shoreline stabilization alternatives at the project site.

The extreme flood stillwater elevations and wave heights have been evaluated using several different data sources and methodologies. The predicted values developed by the USACE North Atlantic Coast Comprehensive Study (NACCS) were used to evaluate storm surge water levels and nearshore significant wave heights. **Table 2** summarizes predicted stillwater elevations under current conditions and conditions associated with projected sea level rise (USACE High Projection) for the years 2040, 2070 and 2100. As shown on **Table 2**, the existing beach and dune (elevations ranging between approximately +3 to +5 feet NAVD88) will be overtopped by a storm surge and significantly eroded with a recurrence interval of about 1-year to 5-years under current sea level conditions (2017; USACE Mean).

For comparison, the top ten observed water levels at the nearby NOAA New London Tide Station and the NOAA Bridgeport Tide Station (in feet, above Mean Higher High Water [MHHW]) are presented in **Table 3**. Coastal flood events include both tropical cyclones (tropical storms to hurricanes) and extratropical storms (nor'easters). The top observed water levels at New London have resulted from six hurricanes, one tropical storm and three nor'easters. The highest observed water levels resulted from hurricanes, with the highest documented flood water level observed during the Hurricane of 1938. Nor'easters are relatively common in New England during the spring, winter and fall. They are less intense than hurricanes but have a large wind field and are long in duration (sometimes lasting several days). Hurricanes occur relatively infrequently in New England. Hurricanes of high intensity with the tracks and landfalls necessary to cause large floods in Old Saybrook are even rarer. However, as noted above hurricanes have historically resulted in the largest storm surge flooding effecting the Old Saybrook area.

The predicted nearshore significant wave heights around Old Saybrook, including near Hepburn Beach, for storms with varying predicted return periods are presented in **Table 4** (based on the USACE NACCS).

NUMERICAL WAVE MODELING RESULTS

Numerical wave modeling was performed by GZA for this project (presented in **Appendix F)** using the Simulating Waves in Nearshore (SWAN) model. Model simulations were performed for typical (prevailing) wave conditions and extreme flood conditions (2-year, 10-year and 100-year storm scenarios). **Appendix F** includes figures illustrating storm surge inundation (lateral extent), wave heights and wave direction for modeled conditions. The figures illustrate wave transformation that occurs as the nearshore waves encroach the site, including the effects of the existing coastal structures.

As shown on the figure in **Appendix F**, the typical prevailing wave (from the southwest) is attenuated within the influence zone of the existing coastal structures (in particular, the offshore breakwater). Refraction and attenuation of the wave occurs locally due to the knee breakwater on the western edge of the project site, accounting in part for the observed beach accretion there. Wave heights there are attenuated (during prevailing conditions) to less than 0.5 foot, consistent with the observation of patches of marsh vegetation there. The existing bathymetry at the "peninsula" at the eastern portion of the site concentrates wave heights and also attenuates wave energy (to less than 0.5 foot in the vicinity of the existing marsh vegetation). Minimal wave attenuation occurs at the beach over most of the central portion of the project site.

Appendix F presents model simulation results for the existing conditions and for the proposed condition (Alternative 5 was modeled and is representative of the expected wave attenuation associated with the Living Shoreline features proposed in Alternatives 5 and 6).

NUMERICAL CIRCULATION MODELING RESULTS

Numerical circulation modeling was performed using the 2-dimensional HEC-RAS model to evaluate the existing tidal circulation under normal tidal conditions and extreme flood conditions (2-year, 10-year and 100-year storm scenarios).

Model simulations were also performed to evaluate the proposed relocation of Crab Creek and culvert replacement to demonstrate that the proposed modifications will not affect the existing hydraulic conditions within the Lynde Point Marsh and pond or increase the coastal flood hazard of adjacent properties. The results are available and presented under separate cover.

SHORELINE STABILIZATION ALTERNATIVES

Several shoreline stabilization alternatives were evaluated. As noted previously, the performance objectives of the shoreline stabilization alternatives are to: 1) mitigate the on-going shoreline erosion; 2) maintain a dune; 3) reduce the probability of a breach of the barrier spit; 4) maintain the Lynde Point Marsh; 5) enhance the existing habitat; 6) maintain natural aesthetic: 7) avoid additional, significant disruption of the natural coastal processes; and 8) provide a range of costs, permitting timelines and levels of protection to consider. Numerical wave modeling was also performed to evaluate proposed alternatives including wave heights and resultant velocities and bottom stresses (for comparison to marsh survivability). The sill dimensions and locations were modified during design to achieve acceptable conditions.

In particular, the goal is to achieve these objectives with minimal use of hard coastal structures and maximum use of a Living Shoreline. The current Connecticut definition of a Living Shoreline is… a shoreline erosion control management practice which also restores, enhances, maintains or creates natural coastal or riparian habitat, functions and processes and also functions to mitigate flooding or shoreline erosion through a continuous land-water interface. Coastal and riparian habitats include but are not limited to intertidal flats, tidal marsh, beach/dune systems, and bluffs. Living shorelines may include structural features that are combined with natural components to attenuate wave energy and currents. Per Public Act 12-101, 2012, Living Shorelines are a feasible, less environmentally damaging alternative to hard structures and utilize a variety of structural and organic materials, such as tidal wetland plants, submerged aquatic vegetation, coir fiber logs, sand fill and stone to provide shoreline protection and maintain or restore coastal resources and habitat.

GZA's development of shoreline stabilization alternatives was also based on the assumption that the existing coastal structures would remain.

No Action Alternative

Modeling of the existing condition indicates that with No Action, the 2-year return period (with assumed coincident peak water level of 4.8 feet NAVD88 and nearshore significant wave heights of about 4 to 5 feet), result in wave collision with the dune – which based on modeling and observed conditions is expected to lead to significant dune recession or complete erosion of the existing dune (and any unreinforced dune of similar geometry and sand volume). Extreme floods with greater recurrence intervals (≥ +/- 5-year recurrence interval) will completely inundate the beach, erode the dune and potentially breach the barrier spit. Observations during previous coastal storms, including the Winter 2019, support this assessment.

Sea level rise will significantly increase the frequency of impactful coastal flood events to at least once per year, requiring ongoing, annual repair of the beach and dune and the Lynde Point Marsh.

Observed shoreline erosion will further contribute to the site vulnerability to breaching of the existing spit. The current distance between the MHW line and the landward shoreline of the Lynde Point Marsh (at the closest point) is currently about 30 to 35 feet. At the currently-observed short term erosion rate of 2.0 feet per year, the spit will be completely eroded in about 15 years and repetitively breached in about 5 years, increasing the overall rate of erosion.

Due to the current vulnerability, a No Action scenario indicates that complete loss of the existing beach spit, significant impacts to the marsh, and an increase in the flood risk is imminent without shoreline stabilization.

Shoreline Stabilization Alternatives

GZA initially developed four conceptual shoreline stabilization alternatives, including one alternative introduced by the DEEP during the initial phase of the project. Following the dune breach during the Winter, 2019, the Lynde Point Land Trust, Borough of Fenwick, GZA and DEEP met and agreed to add alternatives that include the landward relocation of Crab Creek and construction of a larger dune (consistent with existing dunes to the east of the project site) as well as allow room for natural dune migration without disrupting flow within the marsh tidal creek (Crab Creek). Discussions between the stakeholders proceeded to include culvert relocation as part of the project.

The existing conditions plan and conceptual plans presenting each of the alternatives are present in **Appendix I** and include:

- *Alternative 1*: Intertidal Beach Nourishment and Dune Restoration with Plantings. This alternative includes beach nourishment to restore the former dune and marginally elevating the beach to the Mean Low Water line. The beach sand placement would match the existing conditions relative to areas of predominantly sand and cobble beach. This alternative will neither reduce the vulnerability of the site to coastal flood events nor decrease the rate of shoreline erosion. Annual and or bi-annual beach and dune repair and beach nourishment should be anticipated with this alternative. Dune erosion and overwash of the dune sand into the Lynde Point Marsh and Crab Creek should be anticipated on an average bi-annual basis increasing to an annual basis. The risk of a breach of the beach spit is high with this alternative.
- *Alternative 2*: Intertidal Beach Nourishment and Dune Restoration with a Stone Core-Reinforced Dune and Plantings. This alternative is the same as Alternative 1, with the addition of stone core-reinforced dune. This alternative will neither reduce the vulnerability of the site to coastal flood events nor decrease the rate of shoreline erosion. Annual and or bi-annual beach and dune repair (dune cover sand replacement and planting) and beach nourishment should be anticipated with this alternative. Dune erosion and overwash of the dune sand into the Lynde Point Marsh and Crab Creek should be anticipated on an average bi-annual basis increasing to an annual basis. The risk of a breach of the beach spit is significantly reduced with this alternative.
- *Alternative 3*: Dune Restoration with Plantings, Coir Log, Intertidal Sand Fill, New Marsh, Stone Sills and Attached Breakwaters. This alternative reflects the initial concept proposed by the Connecticut DEEP and includes: 1) beach nourishment to restore the former dune; 2) minor filling to about the Mean Low Water line and planting of a tidal marsh, bounded by a low stone sill; and 3) additional attached breakwaters to attenuate wave energy. This alternative is expected to reduce the vulnerability of the site to coastal flood events and decrease the rate of shoreline erosion. The proposed breakwaters represent coastal structures, somewhat inconsistent with a Connecticut Living Shoreline. While the attached breakwaters will attenuate wave action within the project shoreline, there is concern that they may increase erosion to the east.
- *Alternative 4*: Dune Restoration with a Stone Core-Reinforced Dune and Plantings, Cobble and Sand Beach Nourishment, Intertidal Sand Fill, New Marsh and Stone Sills. The alternative includes: 1) beach nourishment to restore the former dune; 2) reinforcement of the dune with a stone core revetment; 3) minor beach nourishment with a sand/cobble mix; and 4) minor filling to about the Mean Low Water line and planting of a tidal marsh, bounded by a moderate stone sill. This alternative uses more robust stone sills to attenuate wave energy. The sills are staggered and aligned to conform to the existing bathymetry and to mitigate negative effects of erosion of adjacent areas. The area available for dune restoration is limited, restricting the dune width and crest elevation.

To reduce the potential for breaching, a stone core revetment is constructed to reinforce the dune. This alternative is expected to reduce the vulnerability of the site to coastal flood events and decrease the rate of shoreline erosion. Erosion of the sand cover in the dune is anticipated on an average bi-annual basis increasing to an annual basis, but the sand overwash volume will be less than a non-reinforced dune. While used for Living Shorelines in other states, preliminary communication with regulators indicate that a stone-reinforced dune may not be considered within the criteria of a Connecticut Living Shoreline. The risk of a breach of the beach spit is reduced with this alternative.

- *Alternative 5*: Relocation of Crab Creek, Dune Restoration and Plantings, Cobble and Sand Beach Nourishment, Intertidal Sand Fill, New Marsh and Stone Sills. This alternative is similar to Alternative 4, with the following addition: a portion of Crab Creek is relocated to provide space to construct a wider, higher dune. This alternative allows greater dune sand volume to mitigate the potential for breach. Dune erosion and overwash of the dune sand into the Lynde Point Marsh should be anticipated on an average bi-annual basis increasing to an annual basis. The risk of a breach of the beach spit is reduced with this alternative. A portion of Crab Creek is relocated, however the creek discharge to the pond is unchanged and the existing culvert is used. The re-aligned sections of Crab Creek will be constructed by excavation to similar creek dimensions. The excavated materials will be used to backfill the replaced sections of Crab Creek.
- *Alternative 6*: Relocation of Crab Creek with a new Culvert, Dune Restoration and Plantings, Cobble and Sand Beach Nourishment, Intertidal Sand Fill, New Marsh and Stone Sills. This alternative is similar to Alternative 5, with the following addition: a new culvert is constructed on Borough of Fenwick property. This alternative allows greater dune sand volume to mitigate the potential for breach. Dune erosion and overwash of the dune sand into the Lynde Point Marsh should be anticipated on an average bi-annual basis increasing to an annual basis. The risk of a breach of the beach spit is reduced with this alternative. The former culvert will be backfilled with an impervious material and left in-place.

The alternatives presented above are intended to stabilize the shoreline, reducing the observed high rate of erosion and preventing negative impacts to Lynde Point Marsh. The approaches to shoreline stabilization range from: 1) on-going beach nourishment; to 2) Living Shorelines with use of hard coastal structures including breakwaters or stone-reinforced dunes; to 3) Living Shorelines with a larger dune (consistent with the existing dune to the east), requiring relocation of portions of Crab Creek. The alternatives differ in construction and maintenance/repair costs; shoreline stabilization performance expectation; and modification of existing habitat.

Each of these alternatives will have vulnerability to future coastal storm damage and will require continual maintenance. This vulnerability indicates the likelihood that regular, post-construction investment will be required for maintenance and repair. A risk analysis has not been performed to establish the optimal design basis flood condition for the project, considering flood and wave probability and construction and maintenance costs. However, site conditions, permitting/regulatory approval and cost will limit the level of protection achievable by the proposed project. In general, reasonable (minimum) project design basis goals for this type of project include:

- Survivability of the new Living Shoreline marsh under conditions associated with floods with a recurrence interval of 10-years or less (that is, floods with an annual recurrence interval greater than 10 years may significantly damage the new marsh).
- Minimal beach erosion under conditions associated with floods with a recurrence interval of 5-year recurrence interval or less (that is, floods with an annual recurrence interval greater than 5 years may significantly erode the beach).

- Minimal dune erosion under conditions associated with floods with a recurrence interval of 5-years (that is, floods with an annual recurrence interval greater than 5-years may significantly erode the dune).
- Reduction of the likelihood of a barrier spit breach, at least to the conditions associated with floods with a recurrence interval of 20-years or less (that is, floods with a recurrence interval greater than 20 years may result in a breach).
- Reduction of the observed, on-going shoreline erosion rates at the project site.
- Avoid negative impacts, such as increased erosion and/or shoreline change, in areas outside of the project site.

A comparative analysis of the alternatives relative to cost, performance (achieving the above-described performance criteria); and consistency with Connecticut Living Shoreline criteria is presented on **Table 5**. The ranks are from 1 to 6, with 1 being the best and 6 being the worst. Preliminary, order-of-magnitude construction costs are also presented. Ranges of costs are presented, pending final design and permit approval.

PERMITTING CONSIDERATIONS

Each of the six alternatives will require local, State and federal environmental approvals as follows:

- Borough of Fenwick Planning and Zoning Commission (PZC) Coastal Site Plan Review;
- USACE Section 404 Permit; and,
- DEEP Certificate of Permission (COP) and 401 Water Quality Certificate.

The entire work area is within the Coastal Boundary; therefore, Coastal Site Plan Review approval is required from the Fenwick PZC.

Work below the spring high tide line (Elevation 3.1 feet NAVD88) is regulated by the U.S. Army Corps of Engineers (USACE) under Section 404 of the Clean Water Act. The type and amount of impact dictates the level of permitting required by the USACE. There are three levels of 404 permitting, in ascending order of complexity and scrutiny: 1) Self-Verification (SV); 2) Pre-Construction Notification (PCN); and, 3) Individual Permit (IP). The SV process is, as its name implies, self-reporting and typically does not involve any USACE review. The PCN review process is typically 4 months and the IP process can take 6-18 months of review. The SV and PCN processes are General Permits (GPs) (i.e., the conditions of the permits are spelled-out and have been agreed to jointly by the USACE and the Connecticut Department of Energy & Environmental Protection (DEEP)). Individual permits impose additional conditions and consider comments by other federal agencies such as National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (FWS) and U.S. Environmental Protection Agency (EPA).

Each of the alternatives could fall under one or more USACE GP categories, including: GP#7, Dredging and/or Beach Nourishment; GP#9 Shoreline & Bank Stabilization; and/or, GP#10, Aquatic Habitat Restoration, Establishment and Enhancement Activities. Each of these has its own specific impact thresholds and conditions. The USACE has discretionary authority as to what level of permitting will be required. This is a unique project that does not neatly fit into any of the General Permit categories.

Work below the Coastal Jurisdiction Line (CJL) (el. 2.9) and/or within tidal wetlands is regulated by DEEP under various permitting programs, depending on the type and degree of impact and the resources present. In general, projects with greater impact require a Structures and Dredging (S&D) Permit and those with lesser impact or those that have an ecological restoration or living shoreline component typically require a Certificate of Permission (COP). The COP process generally involves a 45-90 day DEEP review and the S&D Permit typically involves a 4-6-month review. A Section 401

(Clean Water Act) Water Quality Certificate is also required from DEEP, but this is automatically granted under the GP for most types of projects.

At a recent Living Shorelines Workshop, DEEP encouraged applicants to present living shoreline alternatives for flood and erosion control. This program was authorized under the Connecticut General Statutes (CGS) Section 22a-363(h). On April 5, 2019, GZA requested that DEEP consider this project as a Pilot Project pursuant to Public Act (PA) 12-101, which allows for living shoreline projects to be COP-eligible. On April 25, 2019, DEEP issued a letter stating that the project is eligible (**Appendix H**). The project presented to DEEP for COP-eligibility at that time was Alternative 5 (Living Shoreline); the project now includes relocation of Crab Creek, which is required for the Living Shoreline dune. The final project, with the relocation, may still be COP-eligible.

Below is a summary forecast of the local, State and federal permit requirements for each of the alternatives presented in this report.

- *Alternative 1* would likely qualify for a COP. This alternative would also require a local Coastal Site Plan review approval because the work is within the Coastal Boundary. Alternative 1 could qualify for USACE SVs under GP#7 because the work below MHW entails only beach nourishment. It may also qualify for PCNs under GP#9 if the final design involves less than 500 linear feet of bank stabilization and there is ≤1 cubic yard of fill per linear foot placed between the high tide line (HTL) and mean low water (MLW, Elevation -2.1 feet NAVD88). Additional engineering would be needed to calculate this volume. Finally, this alternative may qualify for SVs under GP#10 (Aquatic Habitat Restoration, Establishment and Enhancement Activities).
- *Alternative 2* would be permitted similarly to Alternative 1. This alternative would likely qualify for a COP. This alternative would also require a local Coastal Site Plan review approval because the work is within the Coastal Boundary. Finally, Alternative 2 could qualify for USACE SVs under GP#7 because the work below MHW entails only beach nourishment. It may also qualify for PCNs under GP#9 if the final design involves less than 500 linear feet of bank stabilization and there is ≤1 cubic yard of fill per linear foot placed between the high tide line (HTL) and mean low water (MLW, Elevation -2.1 feet NAVD88). Additional engineering would be needed to calculate this volume. Finally, this alternative may qualify for SVs under GP#10 (Aquatic Habitat Restoration, Establishment and Enhancement Activities).
- *Alternative 3* is a hybrid solution including hard coastal structure design elements. Alternative 3 will likely qualify for a COP. This alternative would also require a local Coastal Site Plan review approval because the work is within the Coastal Boundary. Alternative 3 could potentially fall under GP#9 and GP#10, but not GP#7 because there is no beach nourishment proposed. Furthermore, this alternative involves placing new and/or expanded structures, i.e. breakwaters and stone sills, to provide wave attenuation in support of salt marsh creation. In all likelihood, the USACE will view this as an Aquatic Habitat Restoration & Enhancement Activity but would require an IP. The USACE will likely review this alternative closely as the creation or expansion of existing waterfront structures, such as breakwaters, is discouraged unless there is critical infrastructure to be protected and there are no practicable non-structural solutions available. This project does not protect infrastructure that the USACE considers to be critical.
- *Alternative 4* is a hybrid solution including hard coastal structure design elements. Alternative 4 will likely qualify for a COP. This alternative will also require a local Coastal Site Plan review approval because the work is within the Coastal Boundary. Alternative 4 could potentially fall under GP#7, GP#9 and GP#10. Furthermore, this alternative involves placing new and/or expanded structures, i.e. stone sills, to provide wave attenuation in support of salt marsh creation. In all likelihood, the USACE will view this as an Aquatic Habitat Restoration &

Enhancement Activity but would require an IP. Alternative 4 has less impact than that of Alternative 3 and would likely be looked upon more favorably by the USACE.

- *Alternative 5* is similar to Alternative 5 for all project components except that: 1) a non-reinforced dune of greater width and height is proposed; and 2) portions of Crab Creek will be relocated to allow dune construction. Alternative 5 will likely qualify for a COP. This alternative would also require a local Coastal Site Plan review approval because the work is within the Coastal Boundary. Alternative 5 may fall under GP#7, GP#9 and GP#10. Furthermore, this alternative involves placing new and/or expanded structures (i.e., stone sills, to provide wave attenuation in support of salt marsh creation). In all likelihood, the USACE will view this as an Aquatic Habitat Restoration & Enhancement Activity but would require an IP. Alternative 5 has less impact than that of Alternative 3 and would likely be looked upon more favorably by the USACE.
- *Alternative 6* is essentially the same as Alternative 5 for all project components except that a new culvert is constructed under Mohegan Avenue to connect the realigned Crab Creek to the pond. This alternative will also require a local Coastal Site Plan review approval because the work is within the Coastal Boundary. In all likelihood, the USACE will view this as an Aquatic Habitat Restoration & Enhancement Activity but will still require an IP due to impacts to existing salt marsh and other intertidal impacts. This alternative was discussed with DEEP, USACE and NMFS in August 2019. In general, all agencies favored the creek relocation.

CONSTRUCTION CONSIDERATIONS

Each of the alternatives will require:

- Site access via Mohegan Avenue.
- A construction laydown area near Mohegan Avenue.
- Sedimentation and erosion control.
- Import of materials including sand, cobbles and boulders (sill and rock core).
- Work within the Coastal Jurisdiction Zone.
- Work within Tidal Wetlands.
- Work within the intertidal zone, including fill placement and use of temporary construction pads.

Alternative 3 would also likely require heavy marine construction activity to construct the breakwaters.

REGULATED RESOURCE IMPACTS

Table 6 compares habitat impacts for the different alternatives. **Table 7** presents an estimate of net impacts to regulated resources for each alternative considered.

TABLES

CURRENT DATUM	FEET (NAVD88)	2040 (USACE HIGH SLR)	2070 (USACE HIGH SLR)	2100 (USACE HIGH SLR)
MSL	-0.30	0.51	2.14	4.43
MHW	0.92 (1.5)	2.12	4.14	6.98
MHHW	1.21 (1.7)	2.48	4.50	7.34
MLW	-1.65 (-2.0)	-1.08	0.96	3.83
MLLW	-1.84 (-2.2)	-1.31	0.73	3.59

*Tidal datums show both New London and the project site (in parentheses). SLR values are referenced to New London. Ref. NOAA Tides and Currents for New London and subordinate station at Saybrook Jetty and predicted using VDATUM.

Table 1: Projected Old Saybrook Tidal Datums Based on USACE High RSLC Projections

	Recurrence Interval								
	1-yr	2-yr	5-yr	10-yr	20-yr	50-yr	100-yr	200-yr	500-yr
2017:									
NOAA MEAN	2.3	3.5	4.4	5.0	5.6	6.6	7.5	8.4	
NOAA UB	2.3	3.7	4.7	5.7	6.7	8.6	10.3	12.6	
NOAA LB	2.3	3.3	4.1	4.5	5.0	5.7	6.2	6.8	
FEMA				5.5		7.7	9.2		15.3
USACE MEAN	3.9	4.8	5.9	6.7	7.4	8.3	9.2	10.3	11.8
USACE UB	6.9	7.7	8.7	9.6	10.4	11.8	12.9	14.1	15.6
USACE LB	0.9	2.0	3.1	3.7	4.3	4.9	5.5	6.4	7.9
2040:									
USACE MEAN (HIGH SLR)	4.9	5.8	6.9	7.7	8.4	9.3	10.2	11.3	12.8
2070:									
USACE MEAN (HIGH SLR)	6.2	7.1	8.2	9.0	9.7	10.6	11.5	12.6	14.1
2100:									
USACE MEAN (HIGH SLR)	10.3	11.2	12.3	13.1	13.8	14.7	15.6	16.7	18.2

Table 2: Summary of Predicted Flood Elevations and Probabilities for the Years 2017, 2040, 2070 and 2100
UB and LB indicate upper and lower bound confidence intervals, respectively (feet NAVD88)

STATION	STATION NAME	1	2	3	4	5
8461490	New London[1]	9/21/1938 7.53 feet	8/31/1954 6.53 feet	10/30/2012 4.89	11/25/1950 4.53 feet	9/14/1944 4.03 feet
		6	7	8	9	10
		9/12/1960 3.83 feet	11/7/1953 3.73 feet	10/31/1991 3.42 feet	8/28/2011 3.39 feet	11/12/1968 3.33 feet
		1	2	3	4	5
8467150	Bridgeport[2]	10/30/2012 5.72	8/28/2011 4.72	12/11/1992 4.72	10/31/1991 4.06	10/25/1980 3.67
		6	7	8	9	10
		3/29/1984 3.29	9/27/1985 3.27	10/19/1996 3.21	11/12/1968 3.20	4/16/2007 3.19

Notes: 1. Station data since 1938; MHHW = +1.21 NAVD88. 2. Station data since 1964; MHHW = +3.48 NAVD88. 3. Water levels not corrected for sea level rise.

Table 3: NOAA Station Top Ten Water Levels (in feet above MHHW)

RECURRENCE INTERVAL (years)	Mean Significant Wave height (feet) near Hepburn Beach
1	3.9
2	4.8
5	5.4
10	5.8
20	6.2
50	6.6
100	6.9
200	7.2
500	7.4

Table 4: Mean Significant Wave Height in feet

Alternative	Performance Rank	Performance Description	Consistency Rank with Living Shoreline Definition	Approximate[1] Construction Cost
Alternative 1	5	Consistent with observed post-storm conditions, this alternative will provide minimal reduction to storm-induced beach and dune erosion. It will also not significantly reduce shoreline change rates. Alternative will likely not meet the project design basis criteria.	2	$400k to $450k
Alternative 2	4	The reinforced dune will reduce dune recession and erosion and reduce the probability of a barrier spit breach. This alternative will not significantly reduce shoreline change rates. Alternative will likely not meet the project design basis criteria.	3	$500 to $620k
Alternative 3	3	While providing greater erosion and shoreline change protection than Alternatives 1 and 2, the use of breakwaters is considered outside of the regulatory definition of a "Living Shoreline." In addition, the breakwaters may further disrupt coastal processes and lead to undesirable impacts east of the project site.	4	$620k to $820k
Alternative 4	2	This alternative provides greater erosion and shoreline protection than Alternatives 1 and 2, without the use of breakwaters. The proposed sills provide some wave attenuation and the established wetlands, along with the sills, will reduce long term shoreline change as well as provide some attenuation of storm wave energy. The placement of the sills close to the shore and conforming to the existing bathymetry reduces potential impact to coastal processes. The placement of cobble beach and wetland creation provides natural habitat consistent with the existing conditions. Stone dune reinforcement (above the CJL) is required to reduce the likelihood of a breach during storm events.	2 (tied with Alternative 1)	$550k to $750k
Alternative 5	1	This alternative provides greater erosion and shoreline protection than Alternatives 1 and 2 without the use of breakwaters. The proposed sills provide wave attenuation and the established wetlands, along with the sills, will reduce long term shoreline change as well as provide some attenuation of storm wave energy. Sill alignment and configuration has been revised based on hydrodynamic modeling to optimize their wave breaking function under predominant conditions and establish a lower energy wave climate landward of the structures to allow marsh growth. The placement of the sills close to the shore and conforming to the existing bathymetry reduces potential impact to coastal processes. The placement of cobble beach and establishment of low marsh behind the sills provides natural habitat consistent with the existing conditions. Crab Creek is relocated to allow for construction of a wider, higher dune.	1	$725k to $775k

Alternative 6	1 (tied with Alt. 5)	This alternative is the same as Alternative 5 except that it includes a culvert replacement to support relocation of Crab Creek.	1 (tied with Alt. 5)	$825k to $875k

Notes: 1. Cost estimates are preliminary and are subject to change during permitting, design revision (if required) and construction bid. Costs do not include: a) warranties; b) final engineering and design; c) construction oversight; or d) permitting. Costs do not include maintenance and repair.

Table 5: Comparison of Alternatives

Habitat Area (sf)	Existing	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6
Low Marsh	42,200	42,200	42,200	62,000	58,130	58,549	60,040
High Marsh	31,040	31,040	31,040	31,040	31,040	31,040	30,720
Maritime Shrub	44,750	44,750	44,750	44,750	44,750	41,853	30,100
Phragmites	4,505	4,505	4,505	4,505	4,505	3,978	0
Dune	20,970	20,970	20,970	20,970	20,970	26,070	26,070
Honeysuckle	1,210	1,210	1,210	1,210	1,210	1,210	970
Washover	5,920	5,665	5,665	5,665	5,665	0	0
Sandy Beach	11,460	29,145	16,768	6,740	0	0	0
Cobble Beach	17,060	673	13,050	13,050	10,310	10,310	10,310
Crab Creek	7,150	7,150	7,150	7,150	7,150	5,654	8,660[3]
Intertidal Stone Sill	-	-	-	8,032	4,920	5,140	5,140
Stone Dune Core	-	-	6,048	-	6,048	-	-

[1] Net fill
[2] Subtidal fill from sills
3 Includes channel area to the west of Mohegan Avenue

Table 6: Summary of Habitat Area (in square feet) for Existing Conditions and Alternatives

Habitat Area (sf)	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6
Low Marsh	0	0	19,800	15,930	16,349	17,840
High Marsh	0	0	0	0	0	-320
Maritime Shrub	0	0	0	0	-2,897	-14,650
Phragmites	0	0	0	0	-527	-4,505
Dune	0	0	0	0	5,100	5,100
Honeysuckle	0	0	0	0	0	-240
Washover	-255	-255	-255	-255	-5,920	-5,920
Sandy Beach	17,685	5,308	-4,720	-11,460	-11,460	-11,460
Cobble Beach	-16,387	-4,010	-4,010	-6,750	-6,750	-6,750
Crab Creek	0	0	0	0	-1,496	79,453
Intertidal Stone Sill	0	0	8,032	4,920	5,140	5,140
Stone Dune Core	0	6,048	0	6,048	0	0

Table 7: Summary of Habitat Area Change (in square feet)

APPENDIX A
LIMITATIONS

USE OF REPORT

1. GeoEnvironmental, Inc. (GZA) prepared this report on behalf of, and for the exclusive use of the Client for the stated purpose(s) and location(s) identified in the Report, including regulatory review. Use of this Report, in whole or in part, at other locations, or for other purposes, may lead to inappropriate conclusions and we do not accept any responsibility for the consequences of such use(s). Further, reliance by any party not identified in the agreement, for any use, without our prior written permission, shall be at that party's sole risk, and without any liability to GZA.

STANDARD OF CARE

2. GZA's findings and conclusions are based on the work conducted as part of the Scope of Services set forth in Proposal for Services and/or Report, and reflect our professional judgment. These findings and conclusions must be considered not as scientific or engineering certainties, but rather as our professional opinions concerning the limited data gathered during the course of our work. If conditions other than those described in this report are found at the subject location(s), or the design has been altered in any way, GZA shall be so notified and afforded the opportunity to revise the report, as appropriate, to reflect the unanticipated changed conditions.
3. GZA's services were performed using the degree of skill and care ordinarily exercised by qualified professionals performing the same type of services, at the same time, under similar conditions, at the same or a similar property. No warranty, expressed or implied, is made.
4. In conducting our work, GZA relied upon certain information made available by public agencies, Client and/or others. GZA did not attempt to independently verify the accuracy or completeness of that information. Inconsistencies in this information which we have noted, if any, are discussed in the Report.

COMPLIANCE WITH CODES AND REGULATIONS

5. We used reasonable care in identifying and interpreting applicable codes and regulations. These codes and regulations are subject to various, and possibly contradictory, interpretations. Compliance with codes and regulations by other parties is beyond our control.

COST ESTIMATES

6. Unless otherwise stated, our cost estimates are only for comparative and general planning purposes. These estimates may involve approximate quantity evaluations. Note that these quantity estimates are not intended to be sufficiently accurate to develop construction bids, or to predict the actual cost of work addressed in this Report. Further, since we have no control over either when the work will take place or the labor and material costs required to plan and execute the anticipated work, our cost estimates were made by relying on our experience, the experience of others, and other sources of readily available information. Actual costs may vary over time and could be significantly more, or less, than Additional Services.
7. GZA recommends that we be retained to provide services during any future: site observations, design, implementation activities, construction and/or property development/redevelopment. This will allow us the opportunity to: i) observe conditions and compliance with our design concepts and opinions; ii) allow for changes in the event that conditions are other than anticipated; iii) provide modifications to our design; and iv) assess the consequences of changes in technologies and/or regulations.

APPENDIX B

PHOTOGRAPHS OF EXISTING CONDITIONS

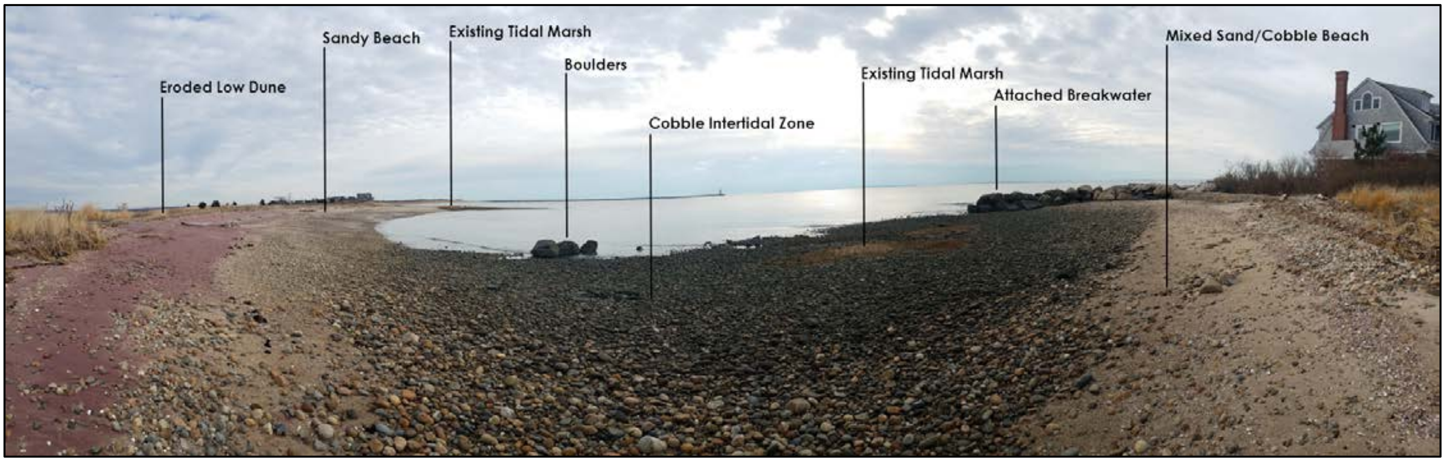


Figure 1 Existing shoreline conditions pre-2019 dune breach (looking south at low tide)

Figure 2 Existing shoreline conditions (looking south at high tide)

Figure 3 Existing dune and marsh conditions pre-2019 dune breach (looking west at mid tide)

Figure 4 Existing shoreline conditions at west end of site (looking northeast at low tide)

Figure 5 Existing attached breakwater at west end of site (looking northeast at mid-tide)

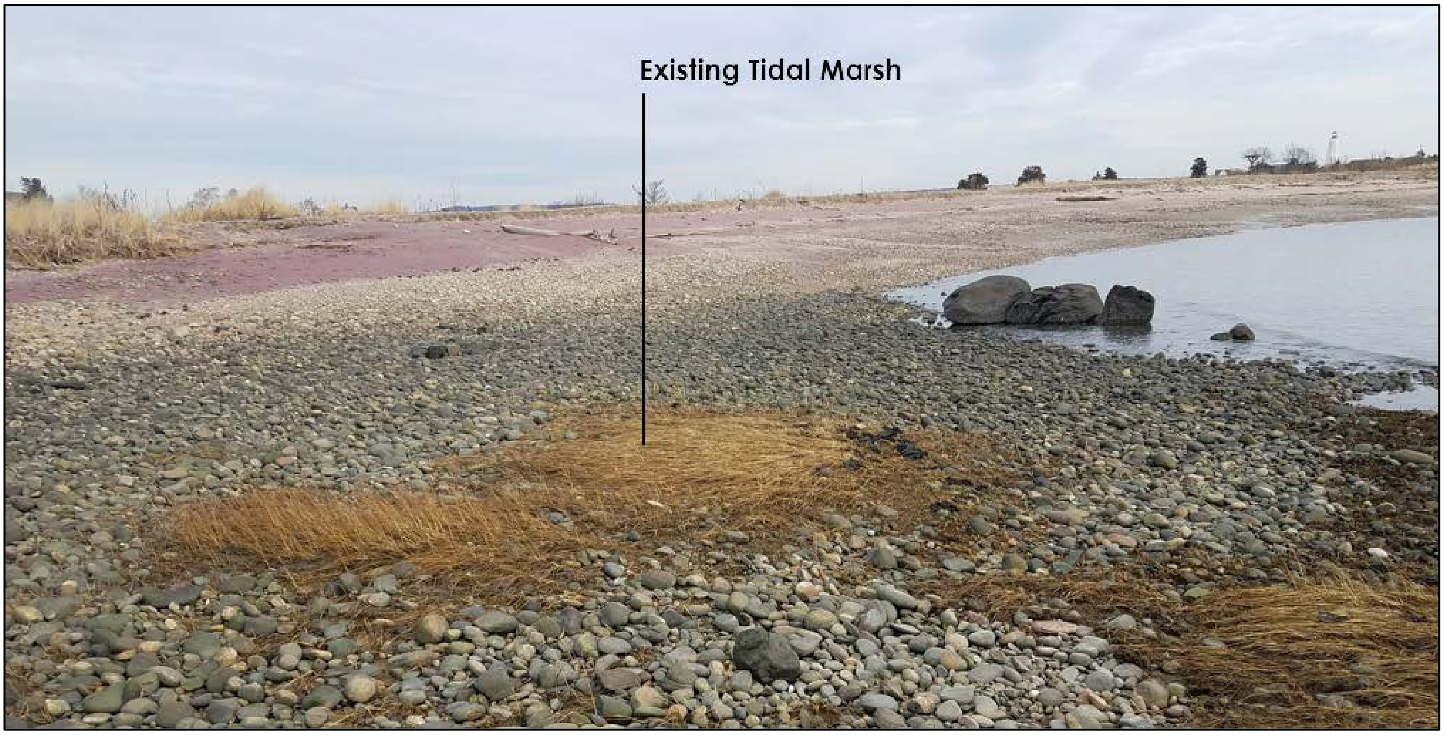


Figure 6 Existing tidal marsh among cobble intertidal zone at west end of site (looking northeast at low tide)

Figure 7 Natural or manmade line of boulders, acting as a sill, contributing to existing marsh growth

Figure 8 Existing Hepburn Dune pre-2019 dune breach (looking west at low tide)

Figure 9 Cobble/Sand composition of existing Hepburn Dune shown after storm-induced erosion (looking north, pre-2019 dune breach)

Figure 10 Existing tidal marsh, cobble intertidal zone at east end of site (looking north at low tide)

Figure 11 Existing tidal marsh, cobble intertidal zone and sandy beach at east end of site (looking west at low tide)

Figure 12 Storm-induced dune breach and infilling of Crab Creek with overwash material looking East (Winter 2019)

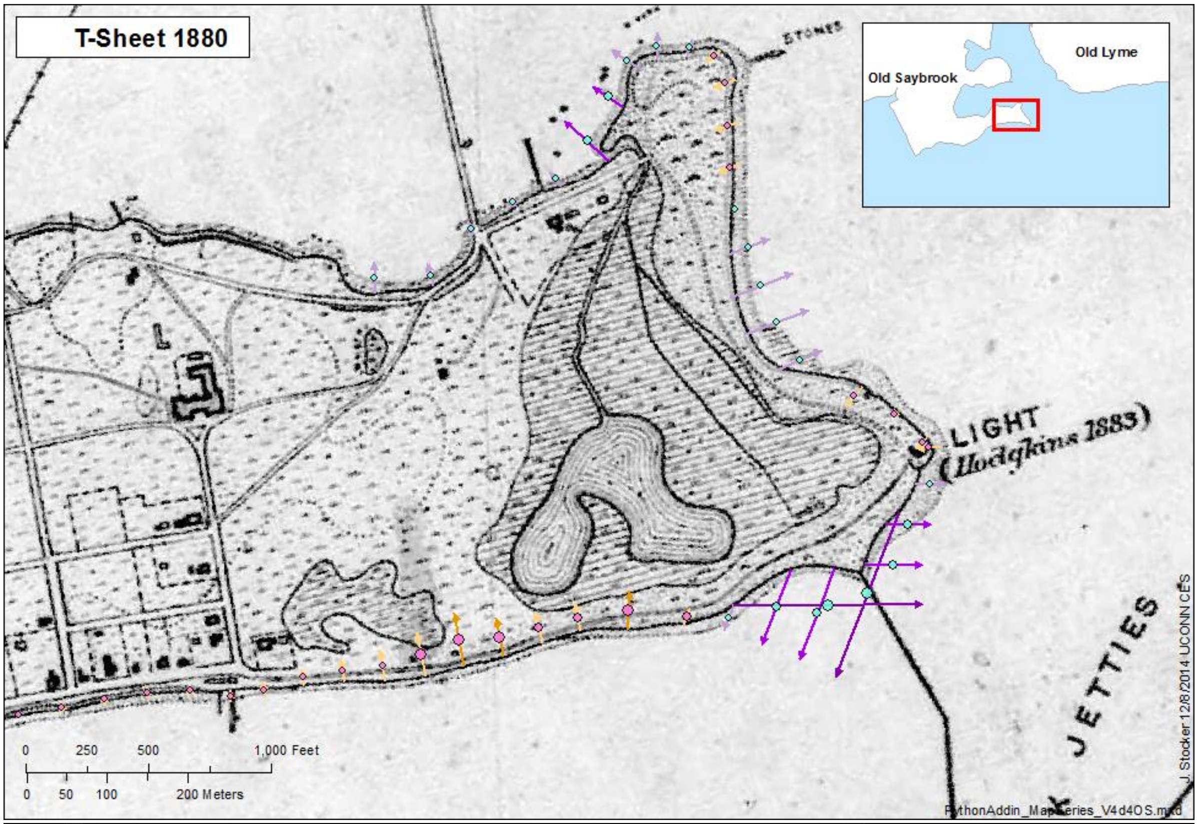
Figure 13 Storm-induced dune breach and infilling of Crab Creek with overwash material looking West (Winter 2019)

Figure 14 2019 Winter Storm Emergency Response Project: Corrugated pipe (western end of the pipe) to restore tidal connectivity and dune restoration

Figure 15 2019 Winter Storm Emergency Response Project: Corrugated pipe (eastern end of the pipe) during ebb flow conditions

APPENDIX C

SHORELINE CHANGE ANALYSIS


T-Sheet 1880
Old Saybrook
Old Lyme
STONES
LIGHT
(Hodgkins 1883)
JETTIES
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


March 1934
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
CT State Library for the scanned aerial photographs. The University of Connecticut Library MAGIC program for the online access to scanned historic images. The Univeristy of Connecitcut Cooperative Extension System for rectifying the images.
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


March 1957
Old Lyme
Old Saybrook
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


March 1965
Old Lyme
Old Saybrook
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


March 1990
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
PythonAddin_MapSeries_V4d4OS.mxd


March 2004
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


June 2005
Old Lyme
Old Saybrook


June 2006
Old Lyme
Old Saybrook
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


June 2008
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


June 2010
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


June 2012
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd


November 2012
Old Saybrook
Old Lyme
0 250 500 1,000 Feet
0 50 100 200 Meters
J. Stocker 12/8/2014 UCONN CES
PythonAddin_MapSeries_V4d4OS.mxd

LEGEND

Short Term Net Shoreline Movement (NSM)

End Point Rate m/yr (1983-2006)

- 0.00 - 0.31
- 0.32 - 1.01
- 1.02 - 2.20
- 2.24 - 3.97
- 4.25 - 6.11

Short Term Net Shoreline Movement (NSM)

End Point Rate m/yr (1983-2006)

- -5.16 - -1.50
- -1.49 - -0.71
- -0.70 - -0.35
- -0.34 - -0.13
- -0.12 - 0.00

HEPBURN DUNE AND MARSH PRESERVATION
LIVING SHORELINE PROJECT
OLD SAYBROOK, CONNECTICUT

SHORT TERM NET SHORELINE MOVEMENT

PREPARED BY: GZA GeoEnvironmental, Inc. Engineers and Scientists www.gza.com

PREPARED FOR: Town of Old Saybrook

PROJ MGR: PM	REVIEWED BY: REV	CHECKED BY: CKD	FIGURE
DESIGNED BY: DES	DRAWN BY: DRN	SCALE: 1" = 200 FEET	1
DATE: 02/28/2018	PROJECT NO. 03.0034368.00	REVISION NO.	SHEET NO.

HEPBURN DUNE AND MARSH PRESERVATION
LIVING SHORELINE PROJECT
OLD SAYBROOK, CONNECTICUT

LONG TERM NET SHORELINE MOVEMENT

PREPARED BY: GZA GeoEnvironmental, Inc. Engineers and Scientists www.gza.com		PREPARED FOR: Town of Old Saybrook	
PROJ MGR: PM	REVIEWED BY: REV	CHECKED BY: CKD	FIGURE
DESIGNED BY: DES	DRAWN BY: DRN	SCALE: 1 " = 200 FEET	2
DATE: 02/28/2018	PROJECT NO. 03.0034368.00	REVISION NO.	SHEET NO.

APPENDIX D

SUMMARY OF PREVIOUS ENGINEERED DUNE CONSTRUCTION and POST-STORM CONDITIONS

Hepburn Dune Restoration Project 2007: Filtrex tubing filled with sand and mulch

Hepburn Dune Restoration Project 2007: Filtrex tubing filled with sand and mulch

Hepburn Dune Restoration Project Fall 2007: Filtrexx tubing covered with sand

Hepburn Dune Restoration Project March 2008: Dunes planted with American beach grass and Switchgrass

Hepburn Dune Restoration Project: Plantings become well established

Hurricane Irene (shown) in 2011 and Superstorm Sandy in 2012 caused extensive damage to the dune restoration project

Following Superstorm Sandy, the dune had been leveled, the Filtrexs tubing was lost, and overwash sediment was deposited in the marsh

APPENDIX E

RESULTS OF WIND AND WAVE ANALYSIS

WIND CLIMATE ANALYSIS

To analyze the local wind patterns (which ultimately drive wave patterns and sediment transport), GZA conducted a statistical analysis of historical wind data (1943-2017) from the Groton-New London Airport located approximately 16 miles to the east. The complete data set is plotted below as a wind rose which shows wind frequency and magnitude throughout the historical record coming from 32 different directional bins (Figure 1). These data show that predominant wind directions here are from the southwest and northwest. When these wind data were further split into four seasons, typical seasonality of winds on the Connecticut coast were identified including winds predominantly from the southwest in the Summer and from the northwest in the Winter with transition periods in the Spring and Fall.

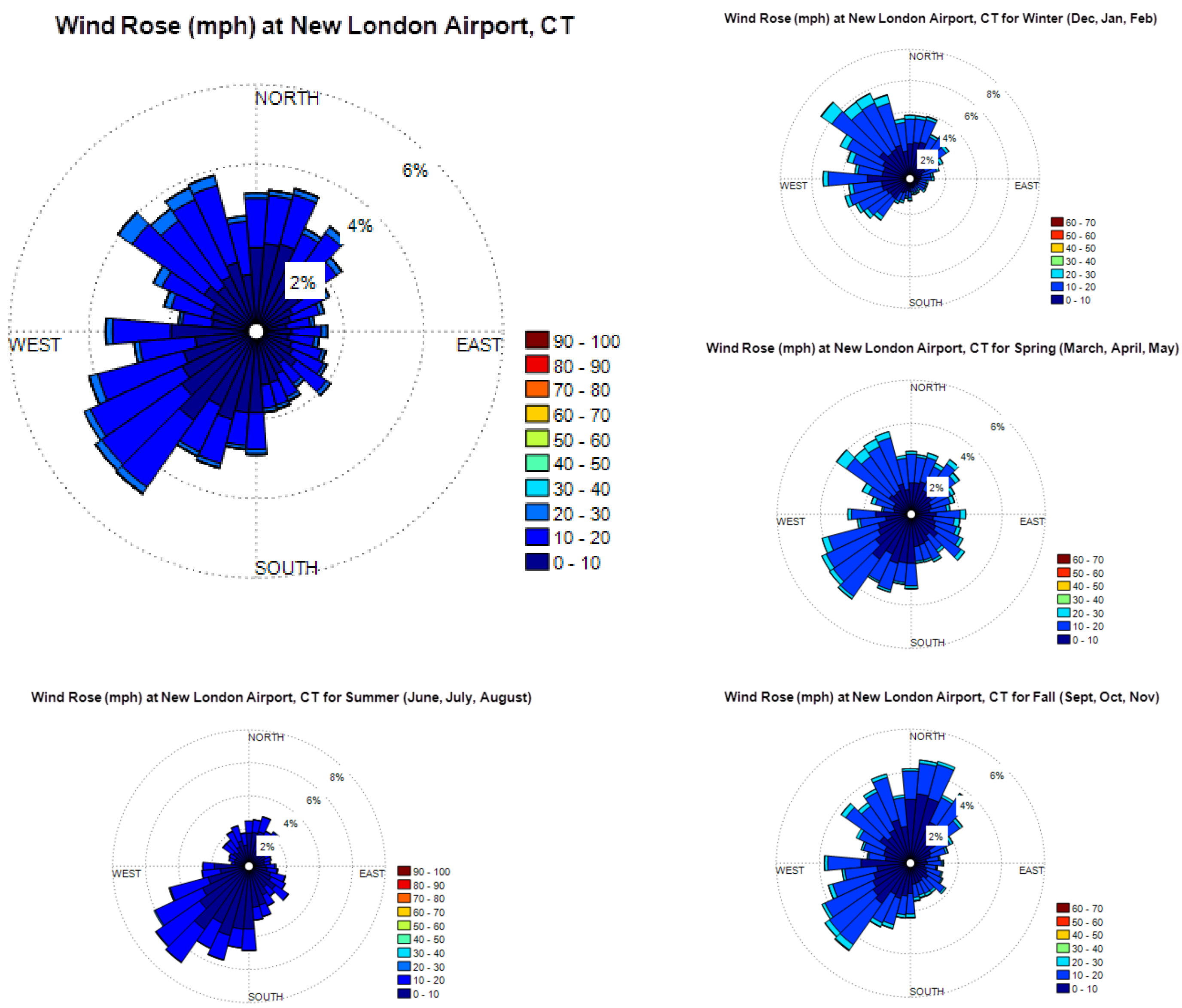


Figure 1. Wind Rose (10 m height, 1-minute sustained wind speed in mph, New London, CT) showing magnitude, direction, and percent frequency of winds from 1943-2017 (top left) and split into four seasons

To determine the direction from which the strongest winds impact the site (and therefore the biggest storms), these data were then divided into six categories of magnitude from winds 0-10 mph to winds greater than 50 mph, and a wind rose was plotted for each category (Figure 2). This analysis shows that the strongest winds impacting the site (> 50 mph) are from the due south.

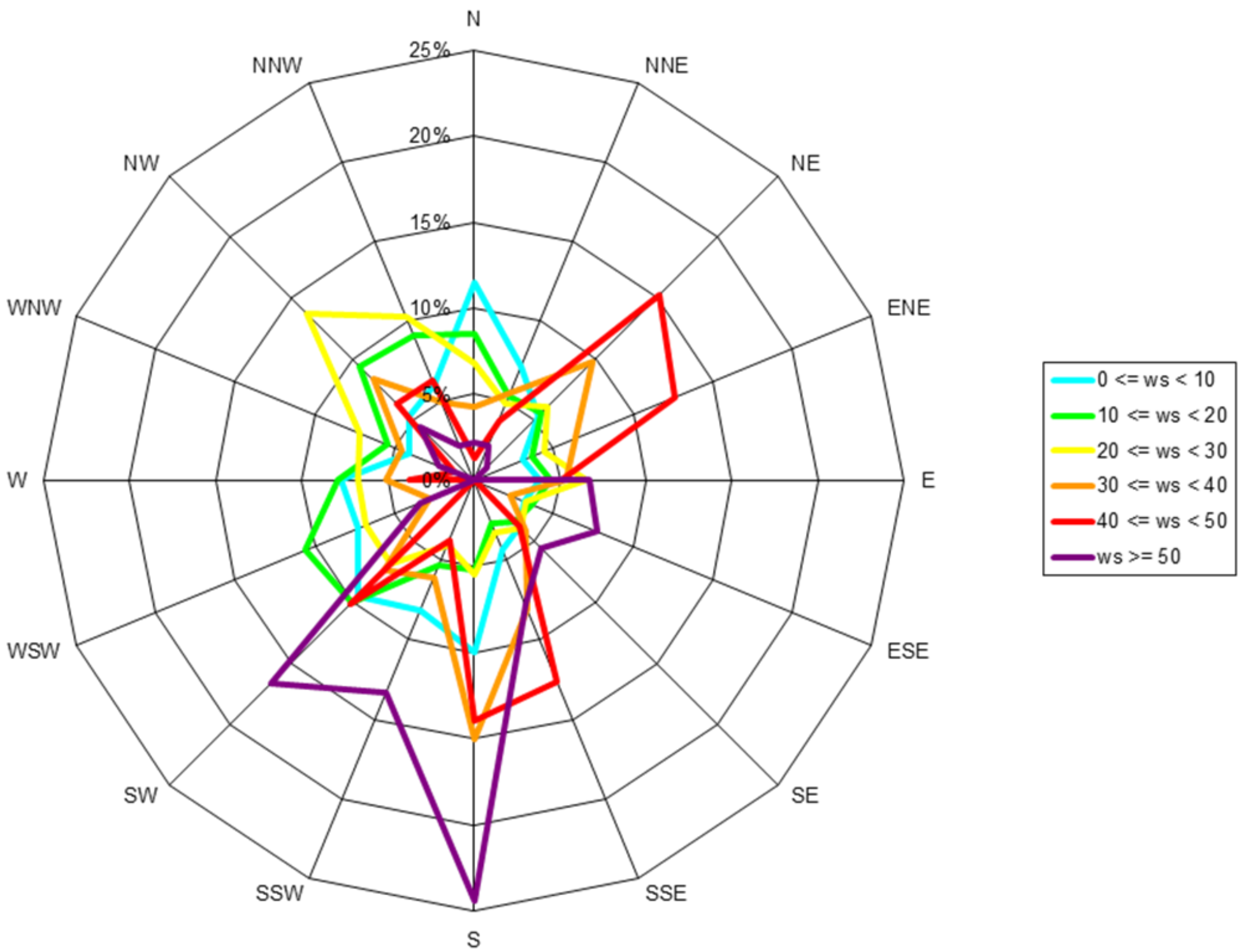


Figure 2. Wind Rose indicating frequency and direction of winds divided into six bins of magnitude from 0-10mph to >50mph (10 m height, 1-minute sustained wind speed in mph, New London, CT)

WAVE CLIMATE ANALYSIS

Wave climate is defined as the distribution of wave parameters (wave height, wave period and wave direction) averaged over a defined time interval at a particular location. Understanding a project site's wave climate is important in designing a successful shore protection strategy. It is useful to understand both low probability higher waves that are associated with storm wave conditions driving short-term shoreline change as well as higher probability lower waves associated with prevailing wave conditions driving long-term shoreline change. For instance, green coastal protection measures such as marshes and sills are often inundated during storm events because of surge. Higher water elevations allow waves to surpass the living shoreline features making wave energy less of a performance concern for their design. For these features, most erosion is observed with the long-term impacts of high probability lower wave heights and thus, these conditions represent the most critical condition for designing living shoreline elements. For design features such as dunes

in which the goal is to prevent a breach, lower probability storm wave conditions that could lead to a breach over a short time period become a more critical design condition.

Since wave climatology data does not exist for this project site and wave climate is driven by local wind patterns, GZA used historical wind data (1943-2017) from the Groton-New London Airport to recreate a historical wave record. This process is known as “hindcasting” and entails calculating wave heights and directions using standard formulas from the USACE Shore Protection Manual (1984) based on known wind speed and direction data, fetch distance and average water depth. For this project, hindcasting of wave data was conducted for seven directional bins (each 22.5 degrees) from which waves impact the project site (Figure 3).

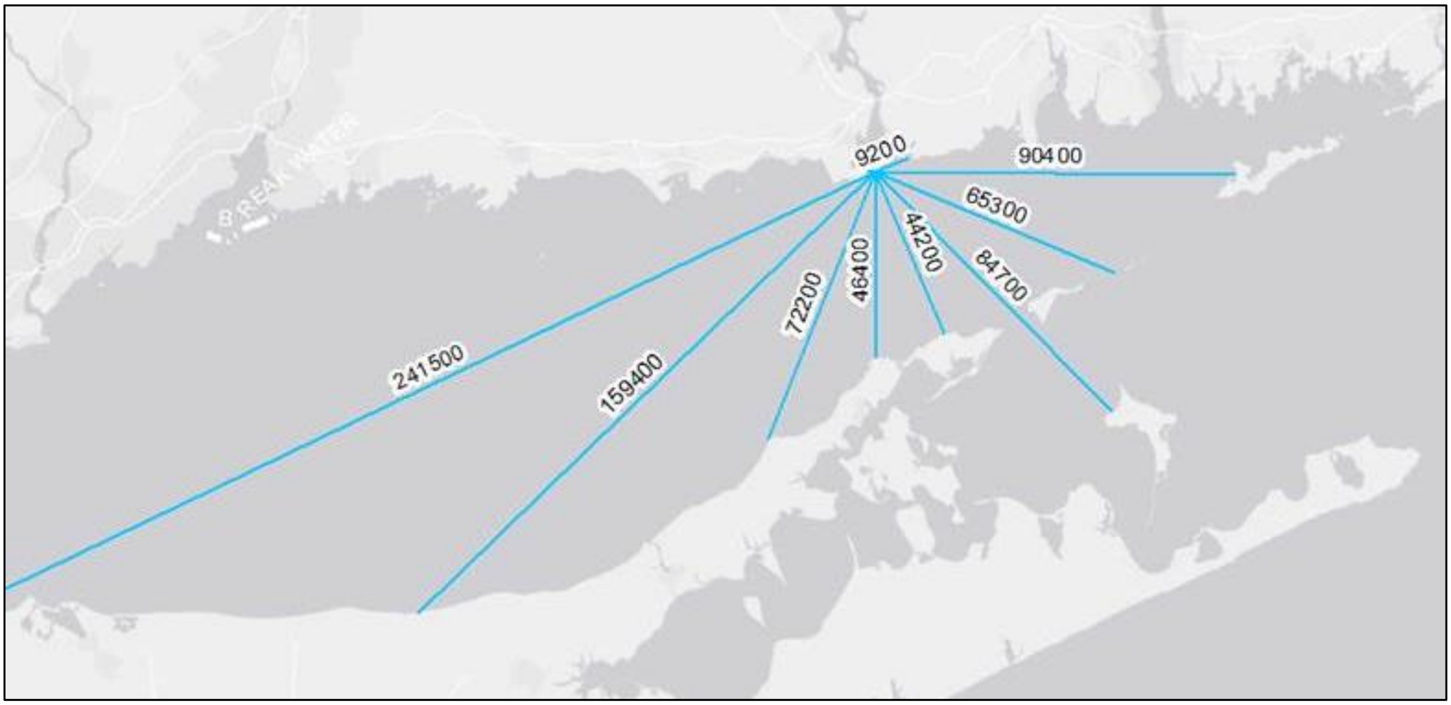


Figure 3. Directional bins and distances (feet) for which wave hindcast statistics were calculated at the project site

Figure 4 illustrates a statistical analysis of wave frequency based on hindcasting data described above within each directional bin. This analysis reveals that for the hindcast data calculated for the site, waves from the west-southwest (shown in light blue) exhibit a higher wave height with more frequency than from other directions. Therefore, waves from the west-southwest are likely the main drivers of shoreline change at the site under predominant conditions.

This statistical analysis of wave frequency is also useful in determining the need for attenuating wave energy at the site with structural elements in order to assure saltmarsh survivability if that is a planned restoration component of a living shoreline project. Research conducted by Shafer (Shafer et. Al, 2003) identifies a threshold wave height for marsh survivability and successful growth. This study estimated through field research that saltmarshes can survive in wave climates in which wave heights exceed 0.14m (0.46ft) no more than 20 percent of the time. This value is also known as the 20-percent exceedance wave height ($H_{20\%}$). For the Hepburn Dune project site (based on statistical analysis of the hindcast wave data described above), the $H_{20\%}$ is 0.27m (0.89ft) as shown in Figure 5. Because the $H_{20\%}$ calculated for this site exceeds 0.14m, the use of wave attenuation structures such as sills or breakwaters will be required to reduce the wave energy environment if saltmarsh restoration is a desired component of the living shoreline design.

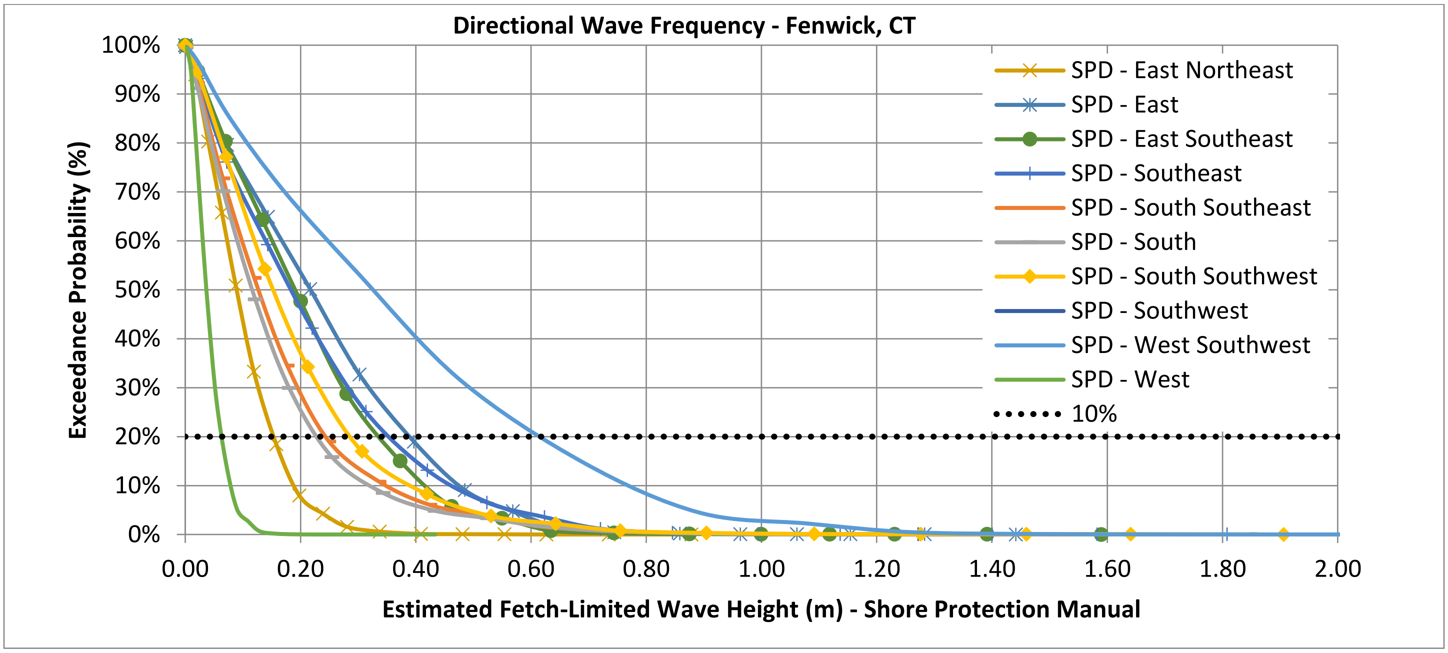


Figure 4. Directional wave frequency statistics and 20% exceedance wave height for each directional bin

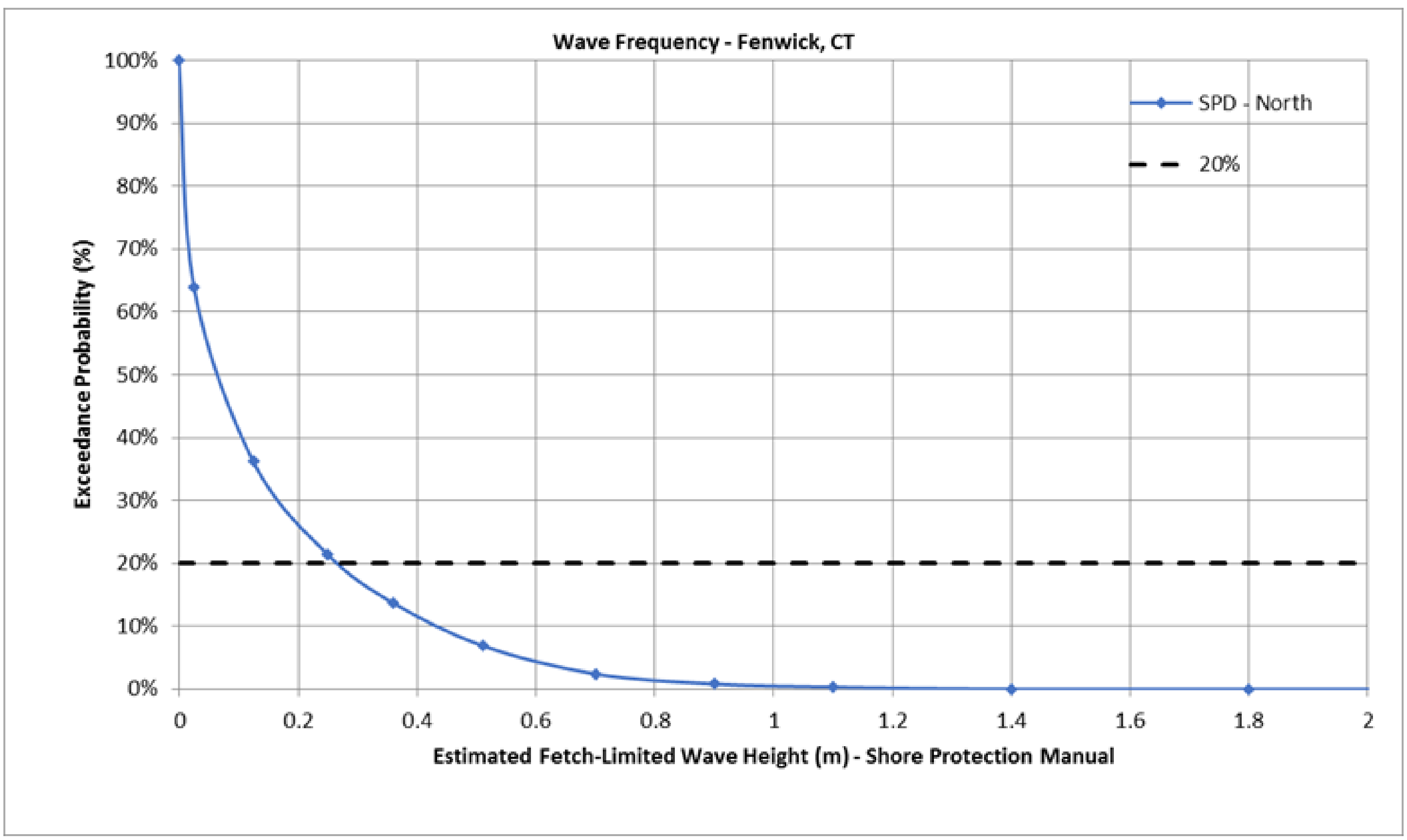
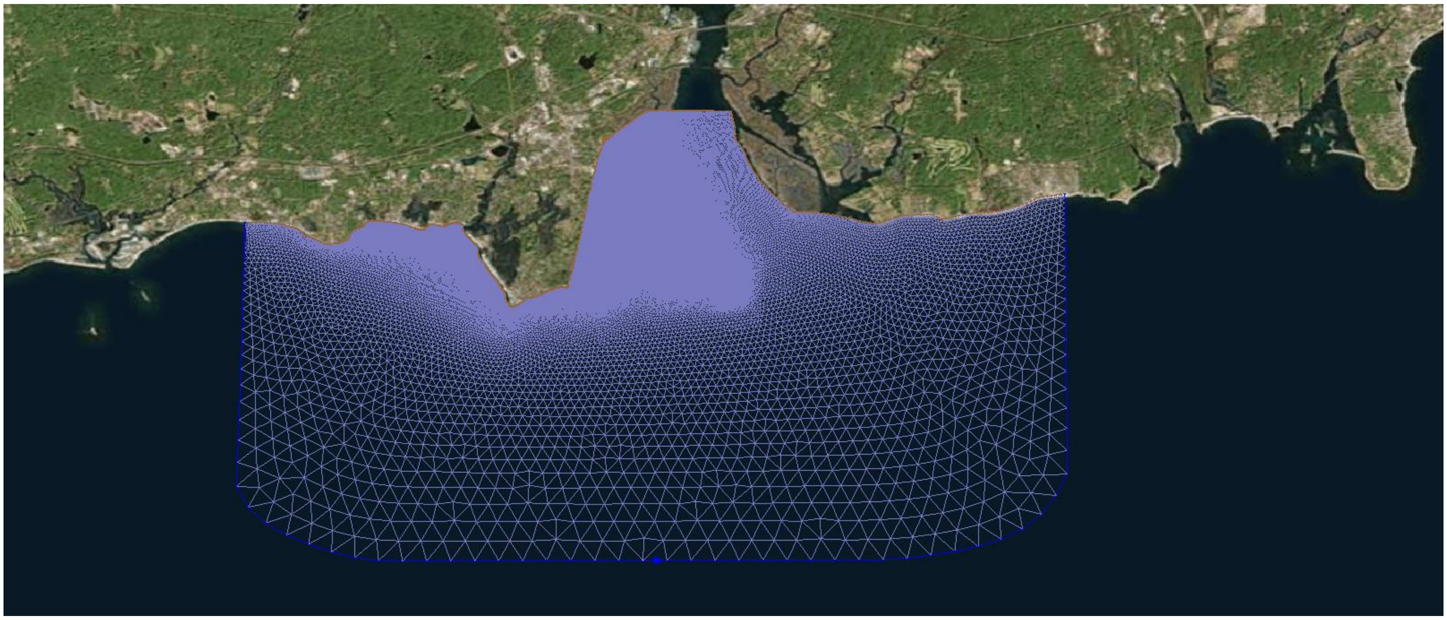


Figure 5. Wave frequency statistics for entire wave data set and 20% exceedance wave height (0.27m)

APPENDIX F

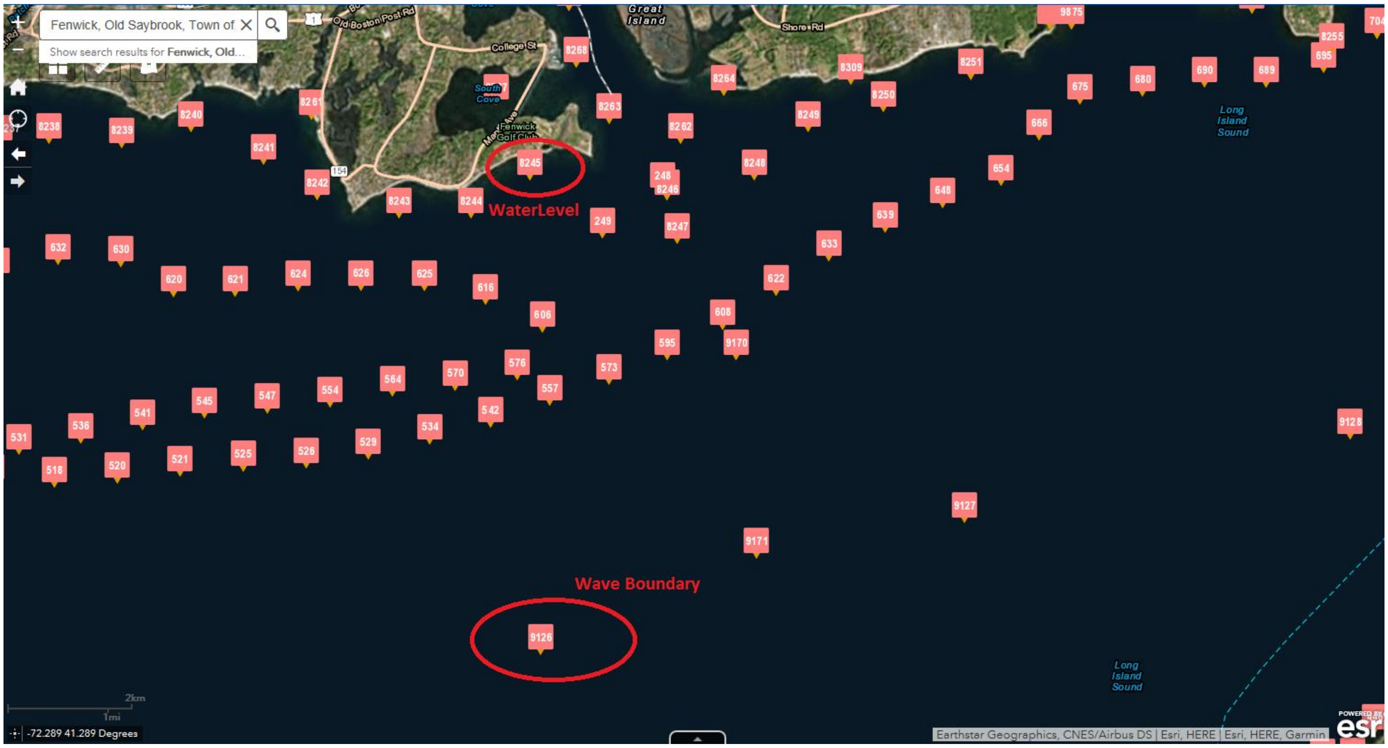
NUMERICAL WAVE MODEL SIMULATION RESULTS

As part of our ongoing Old Saybrook Community Coastal Resilience Study & Infrastructure Evaluation, GZA had already conducted broad scale regional numerical modeling of wave climatology and storm surge using SWAN. This provided financial benefits to the project as the numerical model for the site had already been prepared and only needed refinement of site specific coastal topographic and hydrographic features to complete model setup. The model mesh includes coarser detail hydrography offshore and much finer detail along the shoreline.



Model mesh created for SWAN included digitization of regional hydrography and topography

The next step of the modeling process includes selection of wave conditions and storm events to model. Because design of the living shoreline solution for this site will include elements to address high frequency low wave conditions and low frequency high wave conditions, our modeling team chose to simulate the predominant summer conditions with lower waves approaching from the southwest based on results of the statistical wind and wave analyses described previously and a series of storm events approaching from due south. The storm events chosen were based on research conducted by the United States Army Corps of Engineers (USACE) North Atlantic Comprehensive Coastal Study (NACCS) which conducted extensive numerical modeling and statistical analysis following Hurricane Sandy to determine probabilistic coastal storm and flood risks throughout the North Atlantic at individual points known as "save points". At each one of these points, wave heights and storm surge water levels for the 1-year storm (100% probability of occurring each year) to the 10,000-year storm (0.01% chance of occurring each year) were calculated. The save points from the NACCS study located in the vicinity of the project are shown below. For this study, our modeling team chose to model the 2-year, 10-year and 100-year storm events. Table 1 includes the input parameters for each of the model scenarios run including wind speed, wind direction, water level, wave height and wave direction. Illustrations of modeling results for each of these scenarios are included below. On these illustrations, the extent of inundation is shown overlain on aerial photography as well as significant wave heights (with magnitudes shown as colors) and wave direction (shown as vectors).



Data from NACCS save points 8245 and 9126 were used to provide model input for simulated 2-year, 10-year and 100-year storms at the site.

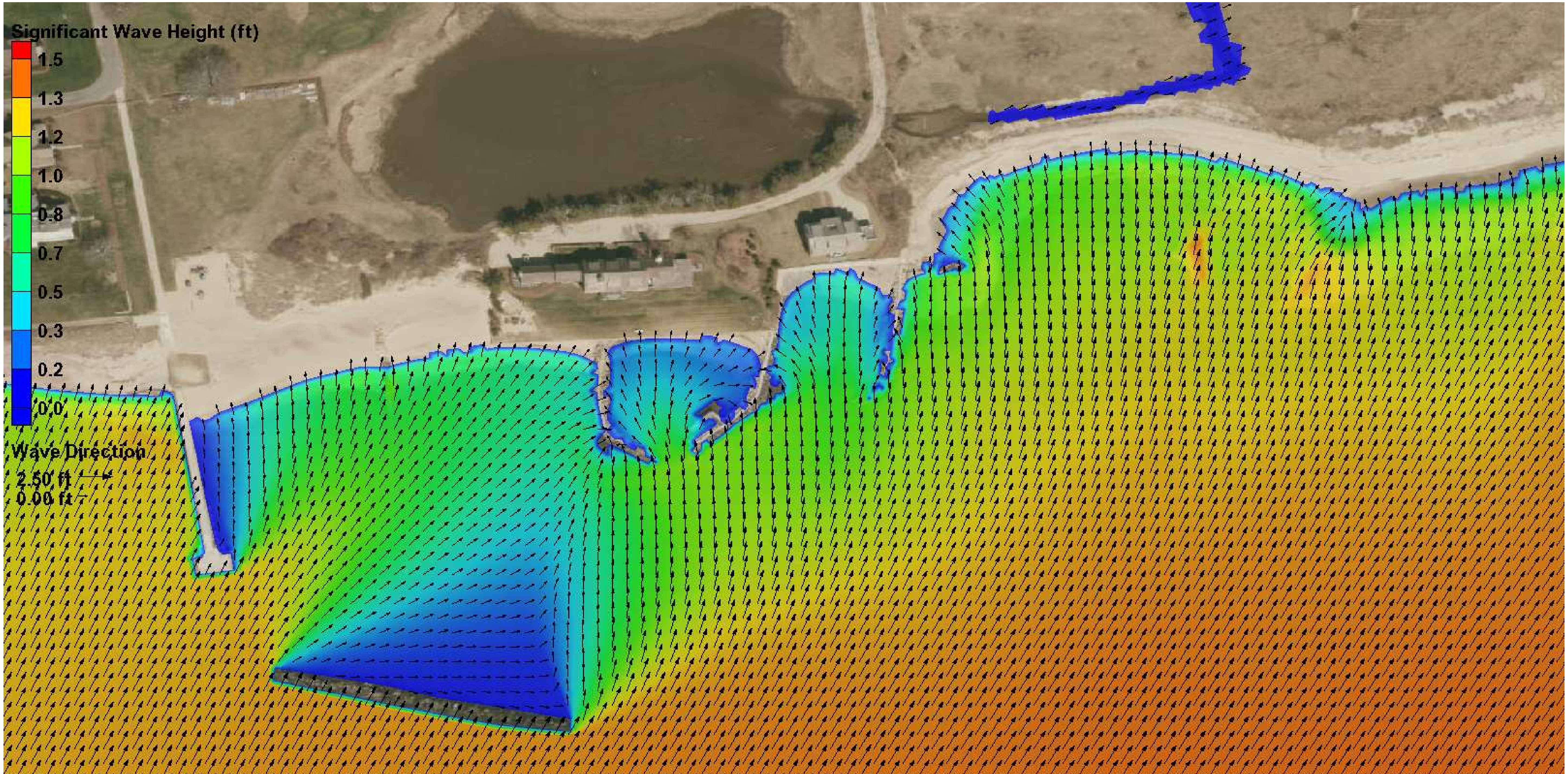
Table 1. SWAN Model Scenarios and Input Parameters

SWAN Modeling Scenario	Wind Speed[1] (mph)	Wind Direction[1]	Water Level[2] (El. NAVD88, ft)	Wave Height[3] (ft)	Wave Direction[3]
Prevailing Summer Conditions	16	WSW	1.5 (MHW)	2.5	WSW
2-Year Storm	35	S	4.8	8.3	S
10-Year Storm	56	S	6.7	10.4	S
100-Year Storm	72	S	9.4	11.9	S

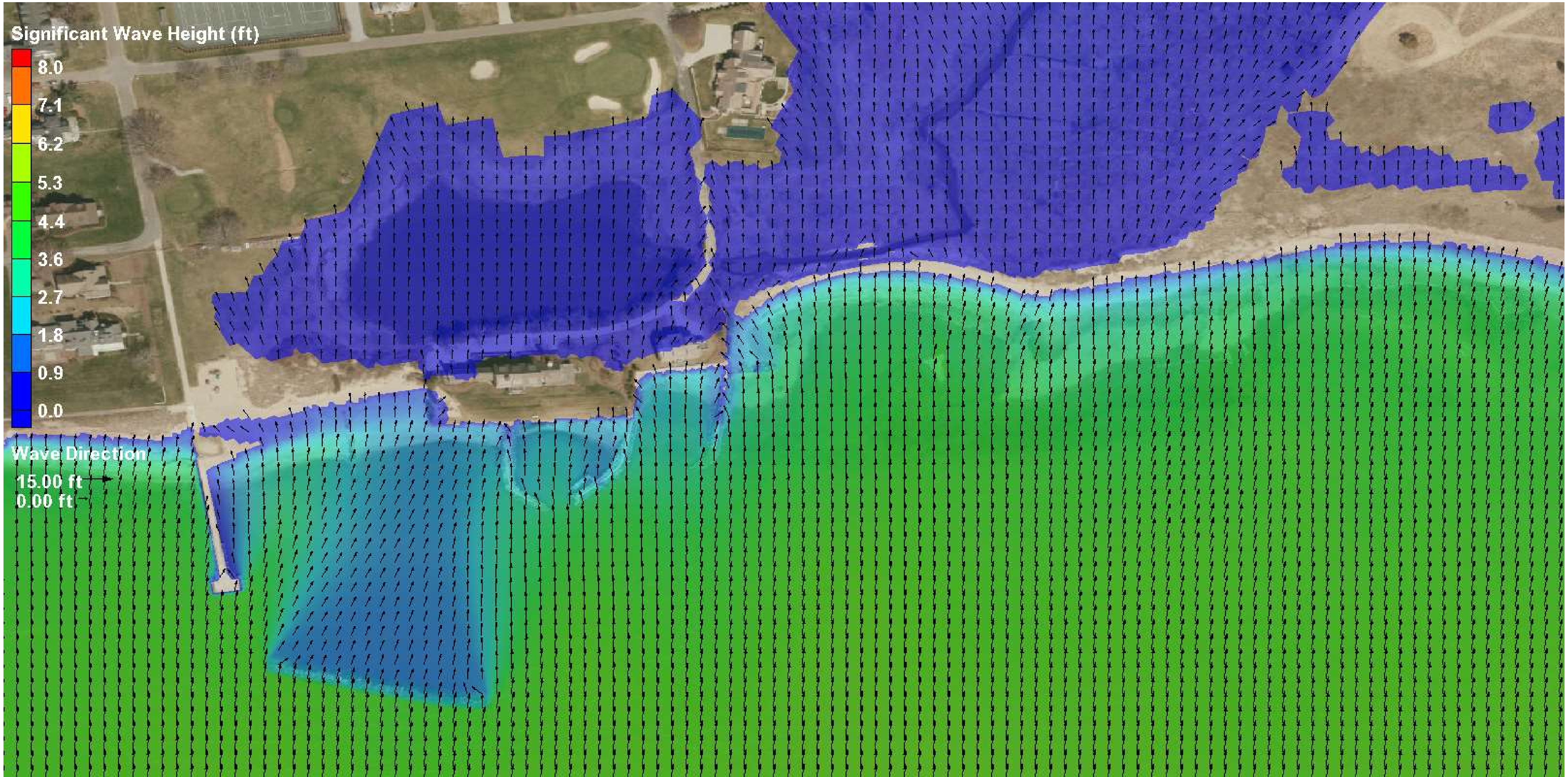
[1] *Based on GZA statistical analysis*

[2] *Based on USACE NACCS save point 8245*

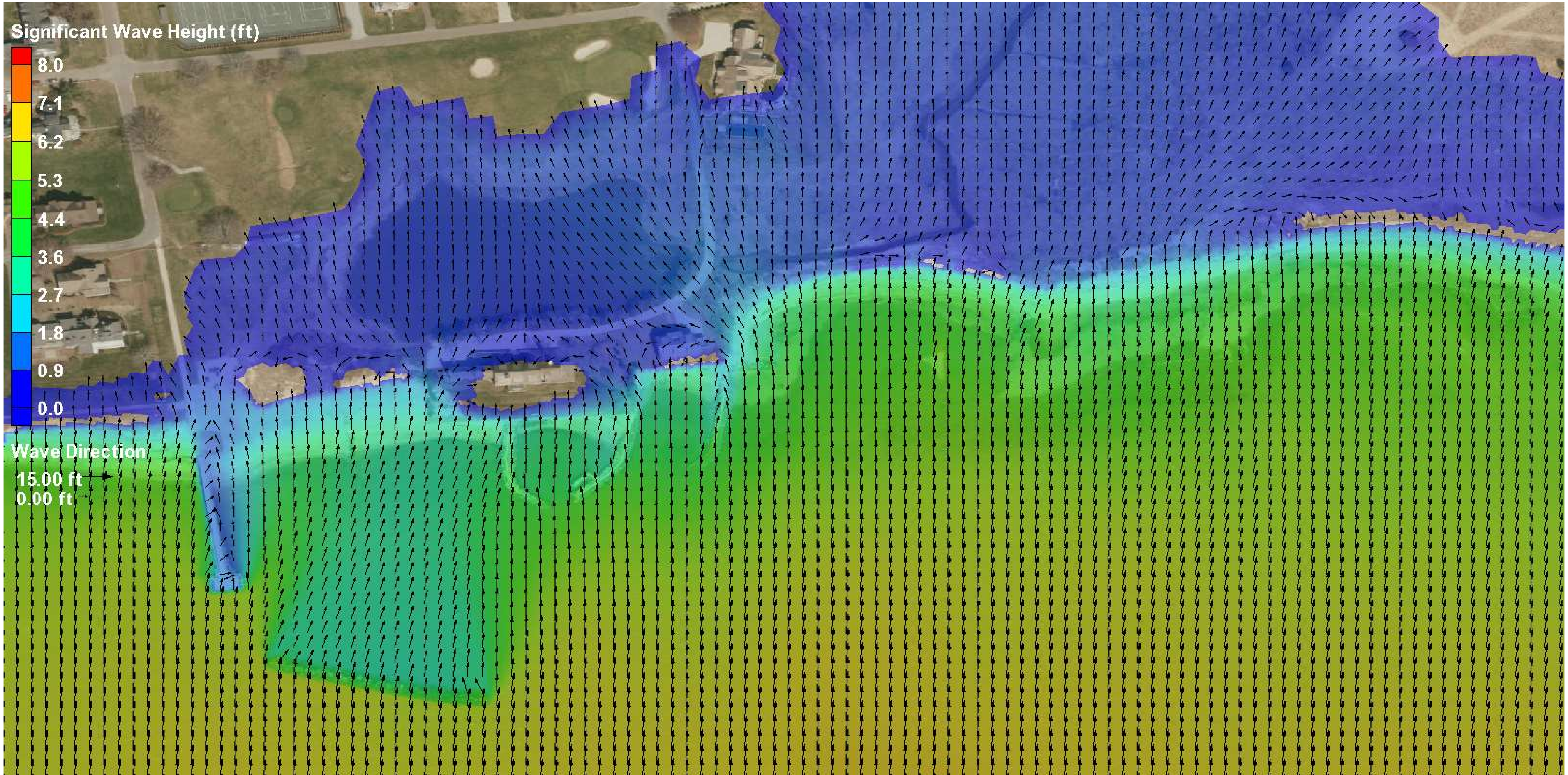
[3] *Based on USACE NACCS save point 9126*



GZA Wave and Storm Surge Modeling
SWAN Scenario: Prevailing Conditions
Model Input: Wind Speed 16 mph | Wind Direction WSW | Water Level 1.5ft NAVD88 (MHW) | Wave Height 2.5ft | Wave Direction WSW



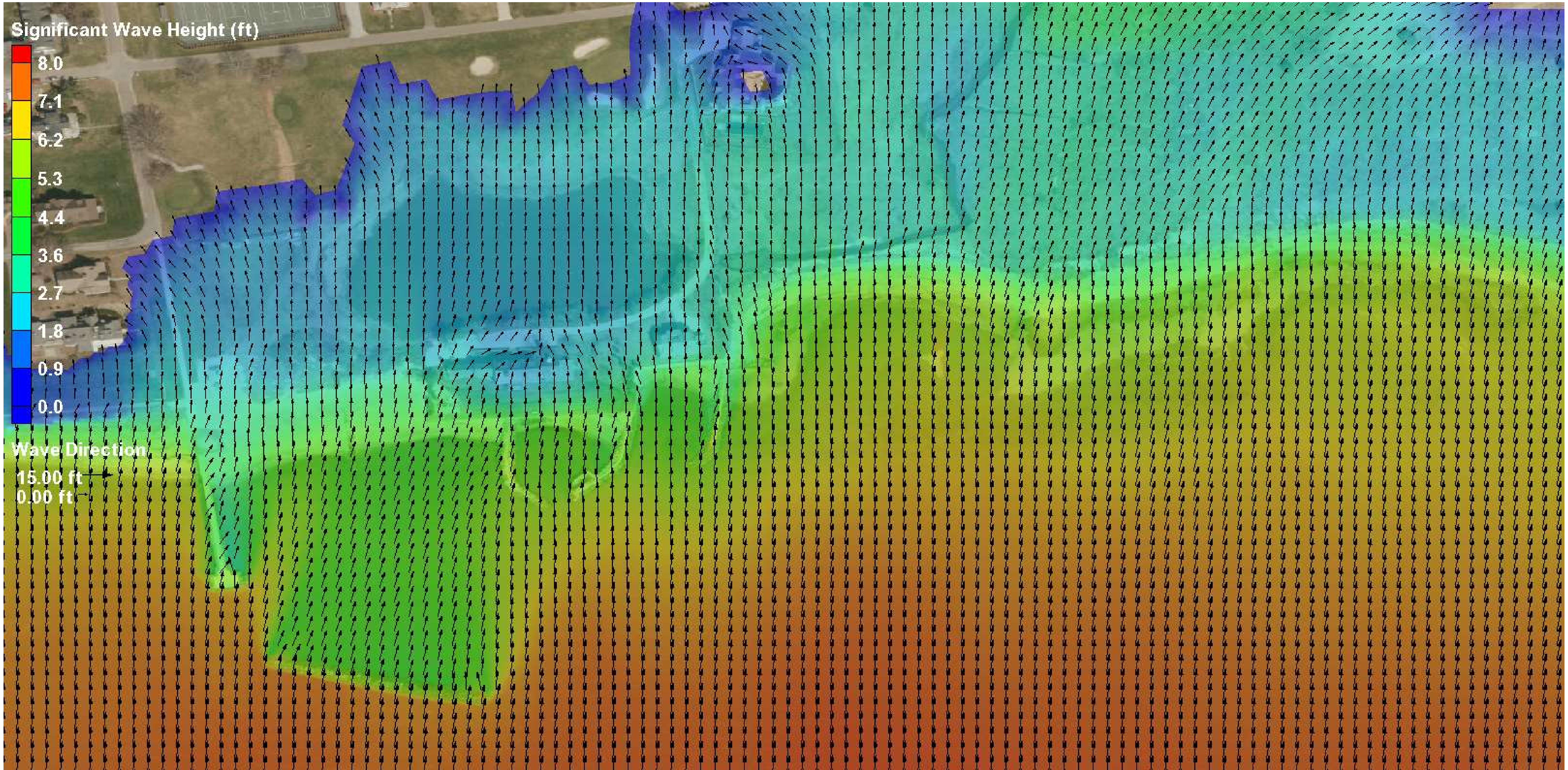
GZA Wave and Storm Surge Modeling
SWAN Scenario: 2-Year Storm
Model Input: Wind Speed 35 mph | Wind Direction S | Water Level 4.8ft NAVD88 | Wave Height 8.3ft | Wave Direction S



GZA Wave and Storm Surge Modeling

SWAN Scenario: 10-Year Storm

Model Input: Wind Speed 56 mph | Wind Direction S | Water Level 6.7ft NAVD88 | Wave Height 10.4ft | Wave Direction S



GZA Wave and Storm Surge Modeling
SWAN Scenario: 100-Year Storm
Model Input: Wind Speed 72 mph | Wind Direction S | Water Level 9.4ft NAVD88 | Wave Height 11.9ft | Wave Direction S

APPENDIX G
ALTERNATIVE 5 NUMERICAL MODEL RESULTS

To refine the design and placement of the proposed stone sills, the conceptual layout was modeled in SWAN under predominant conditions experienced at the site as outlined in Appendix E. The goal in designing the stone sills is to create a wave energy environment landward of the sills in which a marsh environment can grow. Based on research described in this report, a significant wave height of under 0.5 feet under predominant conditions is necessary to sustain a marsh environment (indicated by areas of light to dark blue in SWAN modeling results). When the existing conditions were modeled (Figure 1), areas of existing marsh onsite fell within areas in which SWAN indicated significant wave heights were below this threshold.

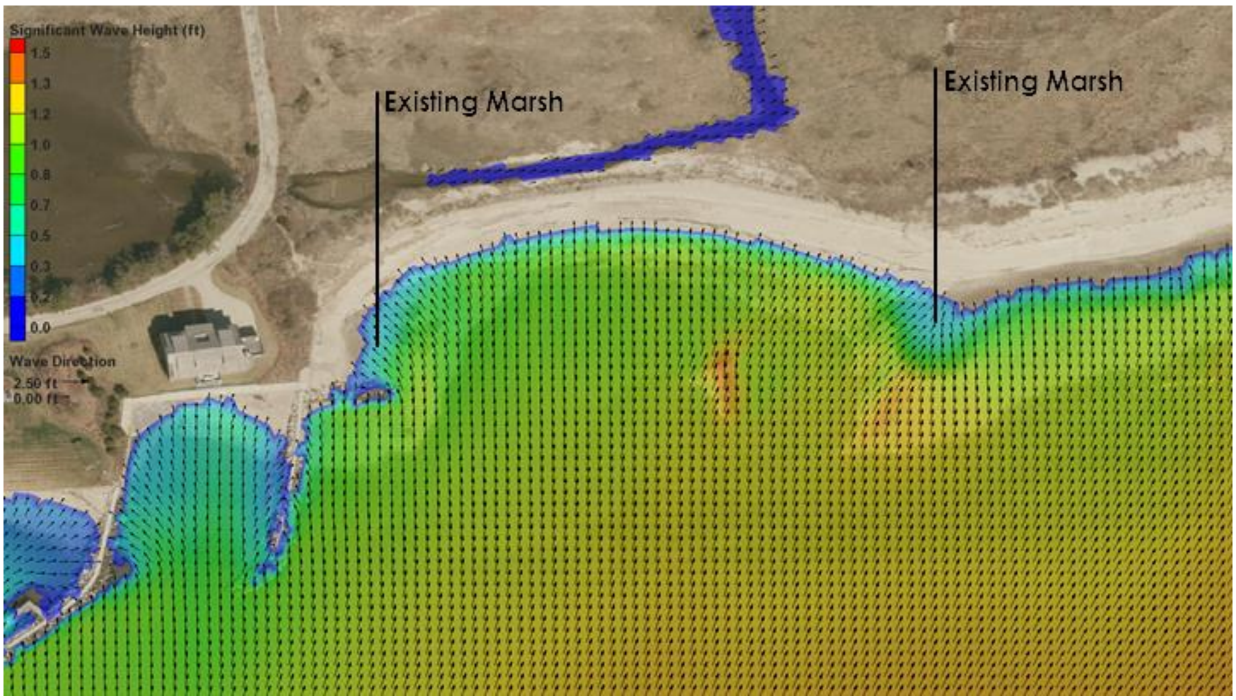


Figure 1. SWAN model of predominant wind and wave conditions under existing conditions (prior to dune breach) and location of existing marsh.

The conceptual layout and height of the proposed sills was then built into the SWAN mesh and the model was rerun under predominant conditions. Results of this model simulation are shown in Figure 2. These results indicated the conceptual alignment of the sills would potentially allow too much wave energy into the marsh environment through the proposed structure gaps pushing the significant wave height above the 0.5 m threshold for marsh growth.

Based on these results, the alignment and overlap of the proposed sills were refined (as shown in Figure 3) and the model simulation was rerun. Crest elevations of the sills remained unchanged, seaward sills were shifted slightly offshore and theirs lengths were increased to create wider overlap zones between seaward and landward sills. These results indicated a more effective dampening of wave energy from this sill configuration resulting in most areas landward of the proposed sills falling below the research-based threshold for marsh growth. Further refinement of the sill configuration is underway to address isolated areas of higher wave energy indicated by this model at the first, second, fourth and eighth gaps from the west.

Model results also present wave heights post construction were almost identical to existing conditions for locations outside of the project area. The results completed to-date indicate that construction of sills are not likely to have significant impacts on wave climate along adjacent shorelines.

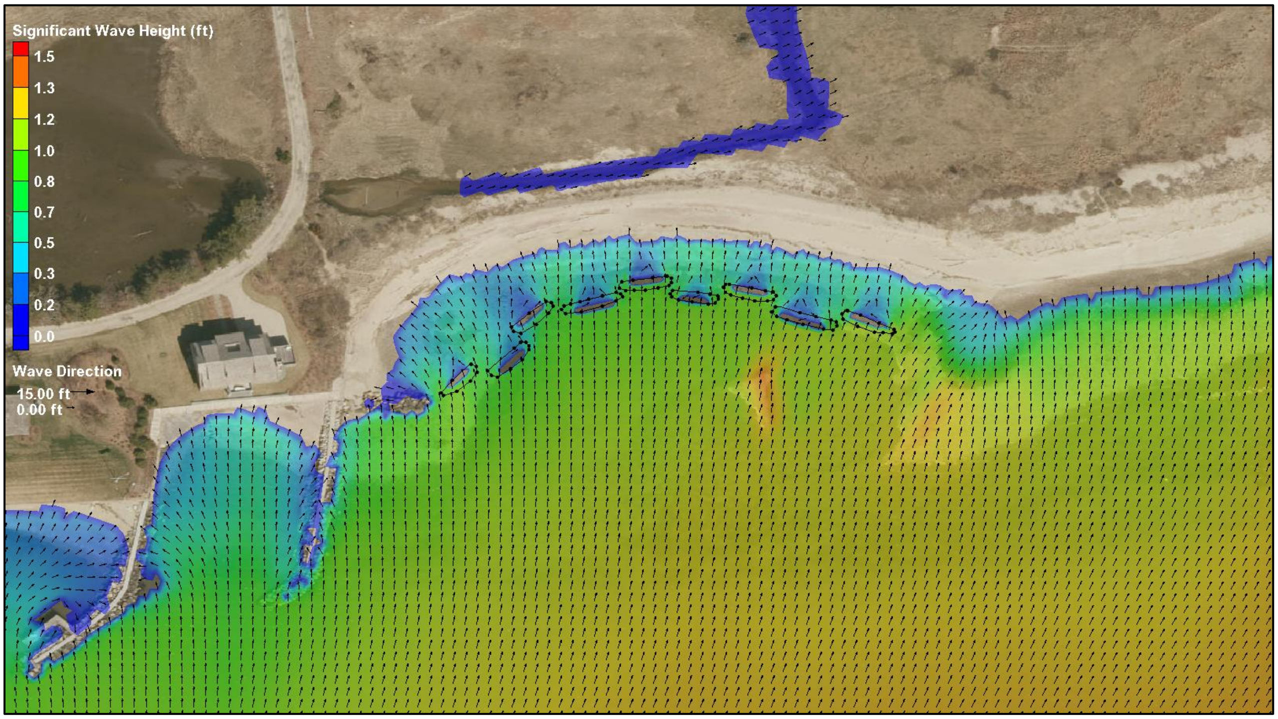


Figure 2. SWAN model of predominant wind and wave conditions for preliminary sill design and layout prior to revision.

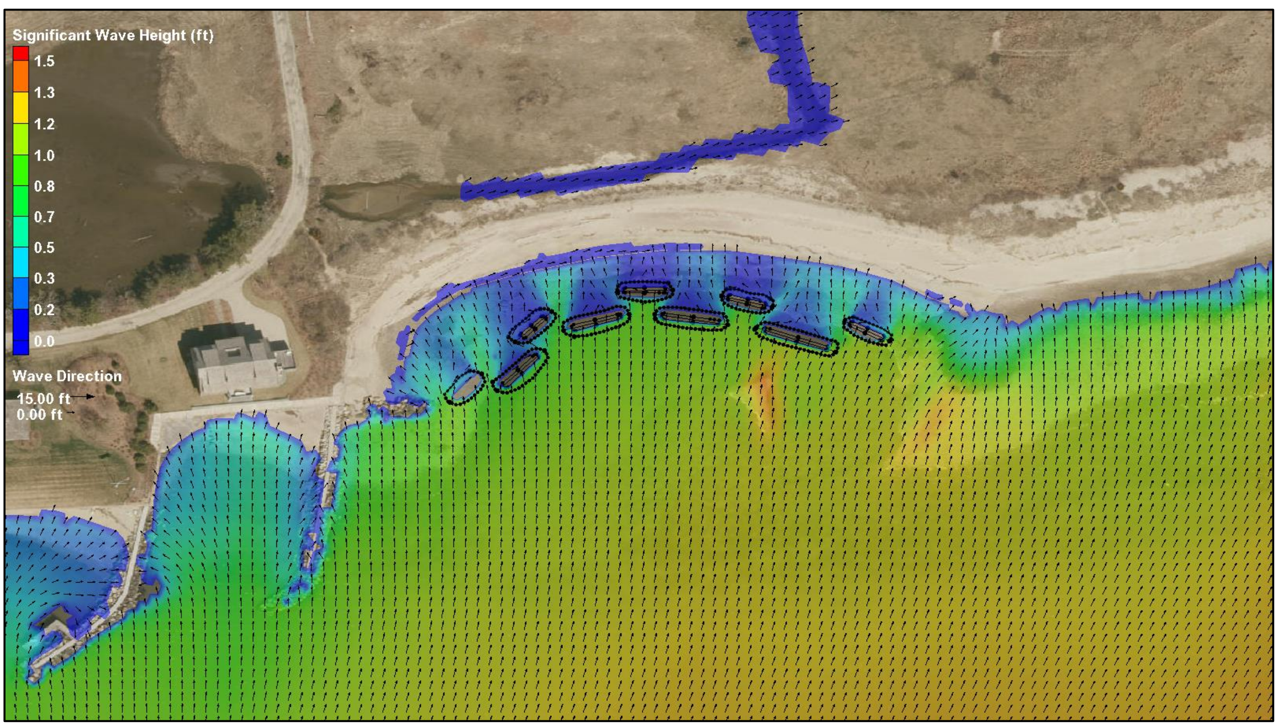


Figure 3. SWAN model of predominant wind and wave conditions for preliminary sill design and layout following revision based on SWAN results.

APPENDIX H
CONNECTICUT DEEP COP LETTER

Connecticut Department of
ENERGY &
ENVIRONMENTAL
PROTECTION

79 Elm Street • Hartford, CT 06106-5127 www.ct.gov/deep Affirmative Action/Equal Opportunity Employer

Mr. Jesse Baldwin, Project Manager
Mr. Stephen Lecco, AICP, CEP, Sr. Environmental Planner
GZA Geoenvironmental, Inc.
655 Winding Brook Drive, Suite 402
Glastonbury, CT 06033

April 25, 2019

Dear Mr. Baldwin and Mr. Lecco:

I am writing in response to your letter to Brian Thompson dated April 5, 2019 received by this office on April 15, 2019 requesting that the Hepburn Preserve Living Shoreline Project be deemed a Pilot Project pursuant to PA 12-101, and thus eligible for expedited permitting process through this office's Certificate of Permission process. Fyi, Brian Thompson is currently Acting Bureau Chief of the Water Protection and Land Reuse Bureau and not currently working within the Land and Water Resources Division.

We are pleased to deem the Hepburn Preserve Living Shoreline Project a Pilot Project pursuant to PA 12-101. We look forward to working with your team towards an acceptable final design which will ideally showcase the values and functions of a successful Living Shoreline enhanced habitat area which will hopefully minimize erosion threats nearshore as well as help preserve Crab Creek and surrounding marsh system and Hepburn Pond.

We look forward to reviewing your final Draft COP application in the near future prior to formal submittal. Please don't hesitate to contact Marcy Balint or Harry Yamalis of my staff with any questions you may have at 860 424 3019.

Sincerely,

Jeff Caiola, Assistant Director
Land and Water Resources Division

CC, by email:
Cindy Patterson (Lynde Point Land Trust)
Marilyn Ozols (Borough of Fenwick)
Andrew Fishk (CT River Conservancy)
Brian P. Thompson, Acting Bureau Chief, WPLR, CT DEEP
Harry Yamalis, LWRD, CT DEEP

APPENDIX I
EXISTING CONDITIONS AND ALTERNATIVES CONCEPT PLANS

LEGEND

- EXISTING BREAKWATER
- EXISTING EXTENT OF COBBLES
- EXISTING SANDY BEACH
- EXISTING COBBLE BEACH
- EXISTING TIDAL MARSH

GENERAL NOTES

1. DATUM: CONTOURS AND POINTS REFERENCE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88). HORIZONTAL DATUM REFERENCES NORTH AMERICAN DATUM OF 1983 (NAD83) CONNECTICUT STATE PLANE COORDINATE SYSTEM, US FOOT.
2. EXISTING CONDITIONS CAD FILE PROVIDED BY ANNINO SURVEY, INC. CAD FILE TITLED "Hepburn-PM-EMAIL.DWG" DATED OCTOBER 2018..
3. ADDITIONAL TOPOGRAPHY AND SURVEY CONTROL LOCATION PERFORMED BY GZA GEOENVIRONMENTAL, INC. AFTER DUNE BREACH ON FEBRUARY, 8 2019. SURVEY CONTROL LOCATIONS USING REAL-TIME KINEMATIC DIFFERENTIAL GLOBAL POSITIONING SYSTEM UNIT (RTK DGPS) TO UPDATE ELEVATIONS AROUND THE DUNE AND THE OVERWASH AREA.
4. AERIAL IMAGE FROM GOOGLE EARTH, DATED OCTOBER 2016. IMAGE SAVED SEPTEMBER 20, 2017.

NO.	ISSUE/DESCRIPTION	BY	DATE

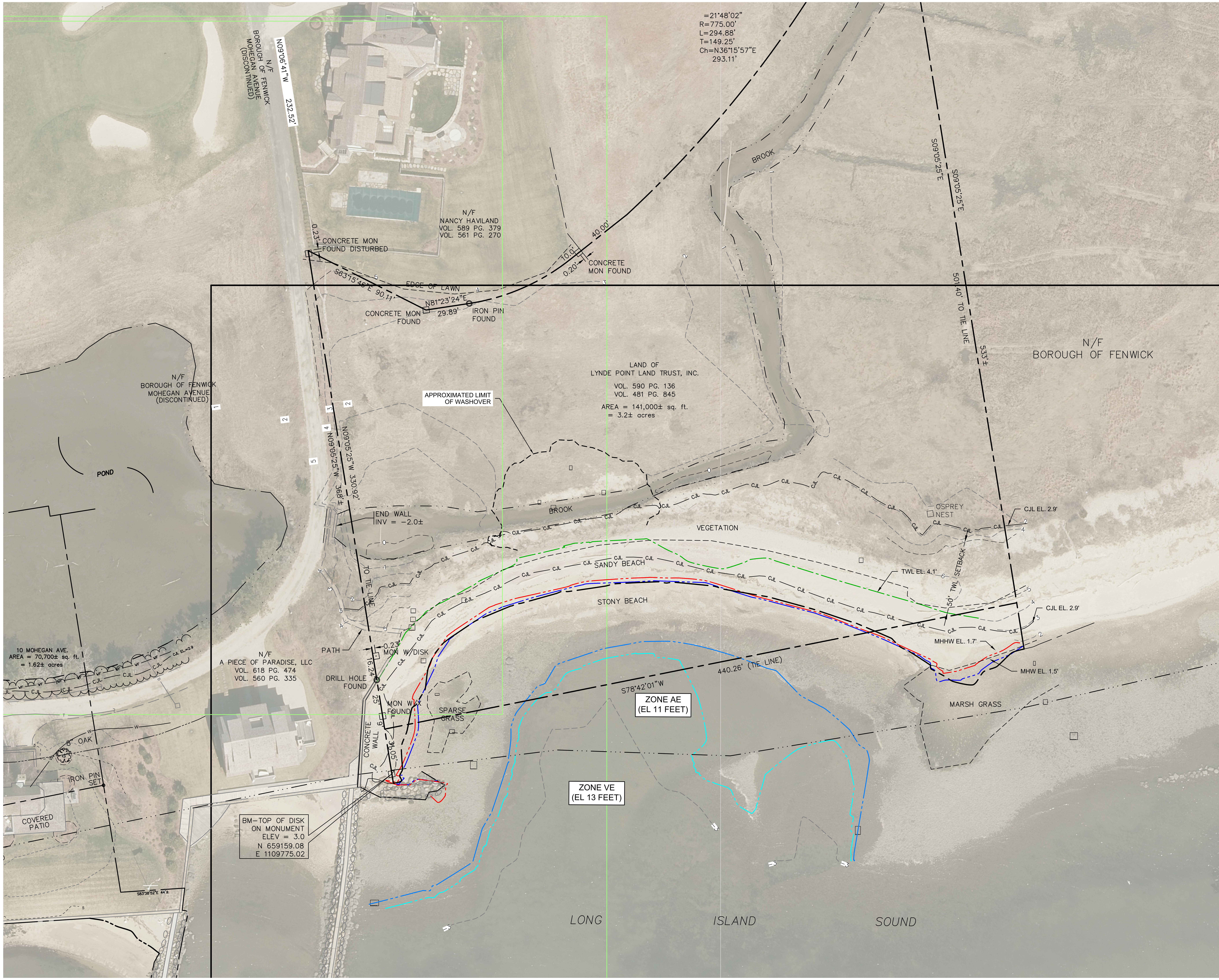
HEPBURN PRESERVE LIVING SHORELINE PROJECT
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

EXISTING CONDITIONS PLAN

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: HM	REVIEWED BY: DCS	CHECKED BY: DCS	FIGURE 1
DESIGNED BY: HM	DRAWN BY: JJZ	SCALE: AS SHOWN	
DATE: AUGUST, 2019	PROJECT NO. 03.0034368.00	REVISION NO. 0	SHEET NO. 1 OF 8



GENERAL NOTES

1. DATUM: CONTOURS AND POINTS REFERENCE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88). HORIZONTAL DATUM REFERENCES NORTH AMERICAN DATUM OF 1983 (NAD83) CONNECTICUT STATE PLANE COORDINATE SYSTEM, US FOOT.
2. EXISTING CONDITIONS AND PROPERTY CAD FILE PROVIDED BY ANNINO SURVEY INC. TITLED "HEPBURN-PM-EMAIL.DWG" DATED OCTOBER 2008
3. AN ELECTRONIC ELEVATION AND PROPERTY SURVEY OF 10 MOHEGAN AVE. LOCATED IN THE SOUTHWEST CORNER OF DRAWINGS WAS PREPARED BY ANNINO SURVEY, LLC FOR BARRY M. GOSIN AND JACQUELINE S. GOSIN. GOSIN-DUNE-EX-071018-EMAIL.DWG, TITLED "GENERAL LOCATION SURVEY" DATED JULY 10, 2018, SCALE 1"=20'
4. ADDITIONAL TOPOGRAPHY AND SURVEY CONTROL LOCATION PERFORMED BY GZA GEOENVIRONMENTAL, INC. ON FEBRUARY 19, 2019 AND MAY 21, 2019 USING REAL-TIME KINEMATIC DIFFERENTIAL GLOBAL POSITIONING SYSTEM UNIT (RTK DGPS) TO REORIENT THE SURVEY DRAWING PROVIDED BY NLJA TO CONNECTICUT STATE PLANE COORDINATE SYSTEM..
5. ADDITIONAL TOPOGRAPHY AND SURVEY CONTROL LOCATION PERFORMED BY GZA GEOENVIRONMENTAL, INC. AFTER DUNE BREACH ON FEBRUARY, 8 2019 USING REAL-TIME KINEMATIC DIFFERENTIAL GLOBAL POSITIONING SYSTEM UNIT (RTK DGPS) TO UPDATE ELEVATIONS AROUND THE DUNE AND THE OVERWASH AREA.
6. AERIAL IMAGE FROM GOOGLE EARTH, DATED OCTOBER 2016. IMAGE SAVED SEPTEMBER 20, 2017.
7. REFER TO FIGURE 1 FOR SURFACE COVERAGE INCLUDING LOCATION OF SAND AND COBBLE BEACH

LEGEND

- PROPERTY/STREET LINE
- FLOOD ZONE BOUNDARY FEMA BASE FLOOD ELEVATION (BFE) INDICATED
- EDGE OF STREAM/POND/
- CJL — COASTAL JURISDICTION LINE (CJL)
- 50-FOOT CJL SETBACK
- WF — WETLAND
- 50-FOOT WETLAND SETBACK
- 0 — EXISTING CONTOUR (MAJOR 5 FOOT INTERVAL)
- 1 — EXISTING CONTOUR (MINOR 1 FOOT INTERVAL)
- TWL EL. 4.1 — CT WETLAND LIMIT
- 50-FT TIDAL WETLAND LIMIT SETBACK
- MHHW EL. 1.7 — MEAN HIGH HIGH WATER
- MHW EL. 1.5 — MEAN HIGH WATER
- MLW EL. -2.0 — MEAN LOW WATER
- BRUSH LINE
- D — STORM SEWER/CATCH BASIN
- E — UNDERGROUND ELECTRIC
- T — UNDERGROUND TELEPHONE
- C — UNDERGROUND CABLE TV

NOTE: REFER TO FIGURE 1 FOR SURFACE COVERAGE INCLUDING LOCATION OF SAND AND COBBLE BEACH

N W E S

PERMITTING ONLY
NOT FOR CONSTRUCTION

0 15' 30' 60' 90'
SCALE IN FEET 1" = 30'

NO.	ISSUE/DESCRIPTION	BY	DATE

HEPBURN PRESERVE LIVING SHORELINE PROJECT
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

POST DUNE BREACH EXISTING CONDITIONS PLAN

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: HM	REVIEWED BY: RJM	CHECKED BY: DCS	FIGURE 2
DESIGNED BY: HM	DRAWN BY: LDT	SCALE: AS SHOWN	
DATE: AUGUST, 2019	PROJECT NO. 34368.01	REVISION NO. 0	SHEET NO. 2 OF 8

LEGEND

- EXISTING BREAKWATER
- EXISTING EXTENT OF COBBLES
- EXISTING TIDAL MARSH
- PROPOSED VEGETATED DUNE
- PROPOSED BEACH NOURISHMENT

GENERAL NOTES

1. DATUM: CONTOURS AND POINTS REFERENCE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88). HORIZONTAL DATUM REFERENCES NORTH AMERICAN DATUM OF 1983 (NAD83) CONNECTICUT STATE PLANE COORDINATE SYSTEM, US FOOT.
2. EXISTING CONDITIONS CAD FILE PROVIDED BY ANNINO SURVEY, INC. CAD FILE TITLED "Hepburn-PM-EMAIL.DWG" DATED OCTOBER 2018.
3. ADDITIONAL TOPOGRAPHY AND SURVEY CONTROL LOCATION PERFORMED BY GZA GEOENVIRONMENTAL, INC. AFTER DUNE BREACH ON FEBRUARY, 8 2019. SURVEY CONTROL LOCATIONS USING REAL-TIME KINEMATIC DIFFERENTIAL GLOBAL POSITIONING SYSTEM UNIT (RTK DGPS) TO UPDATE ELEVATIONS AROUND THE DUNE AND THE OVERWASH AREA.
4. AERIAL IMAGE FROM GOOGLE EARTH, DATED OCTOBER 2016. IMAGE SAVED SEPTEMBER 20, 2017.

NO.	ISSUE/DESCRIPTION	BY	DATE

HEPBURN PRESERVE LIVING SHORELINE PROJECT
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

ALTERNATIVE 1
DUNE RESTORATION & SAND PLACEMENT

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: HM	REVIEWED BY: DCS	CHECKED BY: DCS	FIGURE 3
DESIGNED BY: HM	DRAWN BY: JJZ	SCALE: AS SHOWN	
DATE: AUGUST, 2019	PROJECT NO. 03.0034368.00	REVISION NO. 0	SHEET NO. 3 OF 8

LEGEND

- EXISTING BREAKWATER
- EXISTING EXTENT OF COBBLES
- EXISTING TIDAL MARSH
- PROPOSED VEGETATED DUNE
- PROPOSED COBBLE BEACH
- PROPOSED BEACH NOURISHMENT

GENERAL NOTES

1. DATUM: CONTOURS AND POINTS REFERENCE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88). HORIZONTAL DATUM REFERENCES NORTH AMERICAN DATUM OF 1983 (NAD83) CONNECTICUT STATE PLANE COORDINATE SYSTEM, US FOOT.
2. EXISTING CONDITIONS CAD FILE PROVIDED BY ANNINO SURVEY, INC. CAD FILE TITLED "Hepburn–PM–EMAIL.DWG" DATED OCTOBER 2018.
3. ADDITIONAL TOPOGRAPHY AND SURVEY CONTROL LOCATION PERFORMED BY GZA GEOENVIRONMENTAL, INC. AFTER DUNE BREACH ON FEBRUARY, 8 2019. SURVEY CONTROL LOCATIONS USING REAL–TIME KINEMATIC DIFFERENTIAL GLOBAL POSITIONING SYSTEM UNIT (RTK DGPS) TO UPDATE ELEVATIONS AROUND THE DUNE AND THE OVERWASH AREA.
4. AERIAL IMAGE FROM GOOGLE EARTH, DATED OCTOBER 2016. IMAGE SAVED SEPTEMBER 20, 2017.

NO.	ISSUE/DESCRIPTION	BY	DATE

HEPBURN PRESERVE LIVING SHORELINE PROJECT
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

ALTERNATIVE 2
DUNE RESTORATION WITH STONE CORE,
COBBLE BEACH & SAND PLACEMENT

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: HM	REVIEWED BY: DCS	CHECKED BY: JB	FIGURE 4
DESIGNED BY: HM	DRAWN BY: JJZ	SCALE: AS SHOWN	
DATE: DCS	PROJECT NO. 03.0034368.00	REVISION NO. 0	SHEET NO. 4 OF 8

LEGEND

- EXISTING BREAKWATER
- EXISTING EXTENT OF COBBLES
- EXISTING COBBLE BEACH
- EXISTING SANDY BEACH
- PROPOSED TIDAL MARSH RESTORATION
- PROPOSED COIR LOG
- PROPOSED LOW PROFILE SILL AND ATTACHED BREAKWATER
- EXISTING TIDAL MARSH
- PROPOSED VEGETATED DUNE

GENERAL NOTES

1. DATUM: CONTOURS AND POINTS REFERENCE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88). HORIZONTAL DATUM REFERENCES NORTH AMERICAN DATUM OF 1983 (NAD83) CONNECTICUT STATE PLANE COORDINATE SYSTEM, US FOOT.
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4. AERIAL IMAGE FROM GOOGLE EARTH, DATED OCTOBER 2016. IMAGE SAVED SEPTEMBER 20, 2017.

NO.	ISSUE/DESCRIPTION	BY	DATE

HEPBURN PRESERVE LIVING SHORELINE PROJECT
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

ALTERNATIVE 3
DEEP SUGGESTED PLAN

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: HM	REVIEWED BY: DCS	CHECKED BY: DCS	FIGURE 5
DESIGNED BY: HM	DRAWN BY: JJZ	SCALE: AS SHOWN	
DATE: AUGUST, 2019	PROJECT NO. 03.0034368.00	REVISION NO. 0	SHEET NO. 5 OF 8

LEGEND

- EXISTING BREAKWATER
- EXISTING EXTENT OF COBBLES
- EXISTING TIDAL MARSH
- PROPOSED VEGETATED DUNE
- PROPOSED COBBLE BEACH
- PROPOSED TIDAL MARSH RESTORATION
- PROPOSED MARSH SILL

GENERAL NOTES

1. DATUM: CONTOURS AND POINTS REFERENCE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88). HORIZONTAL DATUM REFERENCES NORTH AMERICAN DATUM OF 1983 (NAD83) CONNECTICUT STATE PLANE COORDINATE SYSTEM, US FOOT.
2. EXISTING CONDITIONS CAD FILE PROVIDED BY ANNINO SURVEY, INC. CAD FILE TITLED "Hepburn-PM-EMAIL.DWG" DATED OCTOBER 2018.
3. ADDITIONAL TOPOGRAPHY AND SURVEY CONTROL LOCATION PERFORMED BY GZA GEOENVIRONMENTAL, INC. AFTER DUNE BREACH ON FEBRUARY, 8 2019. SURVEY CONTROL LOCATIONS USING REAL-TIME KINEMATIC DIFFERENTIAL GLOBAL POSITIONING SYSTEM UNIT (RTK DGPS) TO UPDATE ELEVATIONS AROUND THE DUNE AND THE OVERWASH AREA.
4. AERIAL IMAGE FROM GOOGLE EARTH, DATED OCTOBER 2016. IMAGE SAVED SEPTEMBER 20, 2017.

NO.	ISSUE/DESCRIPTION	BY	DATE

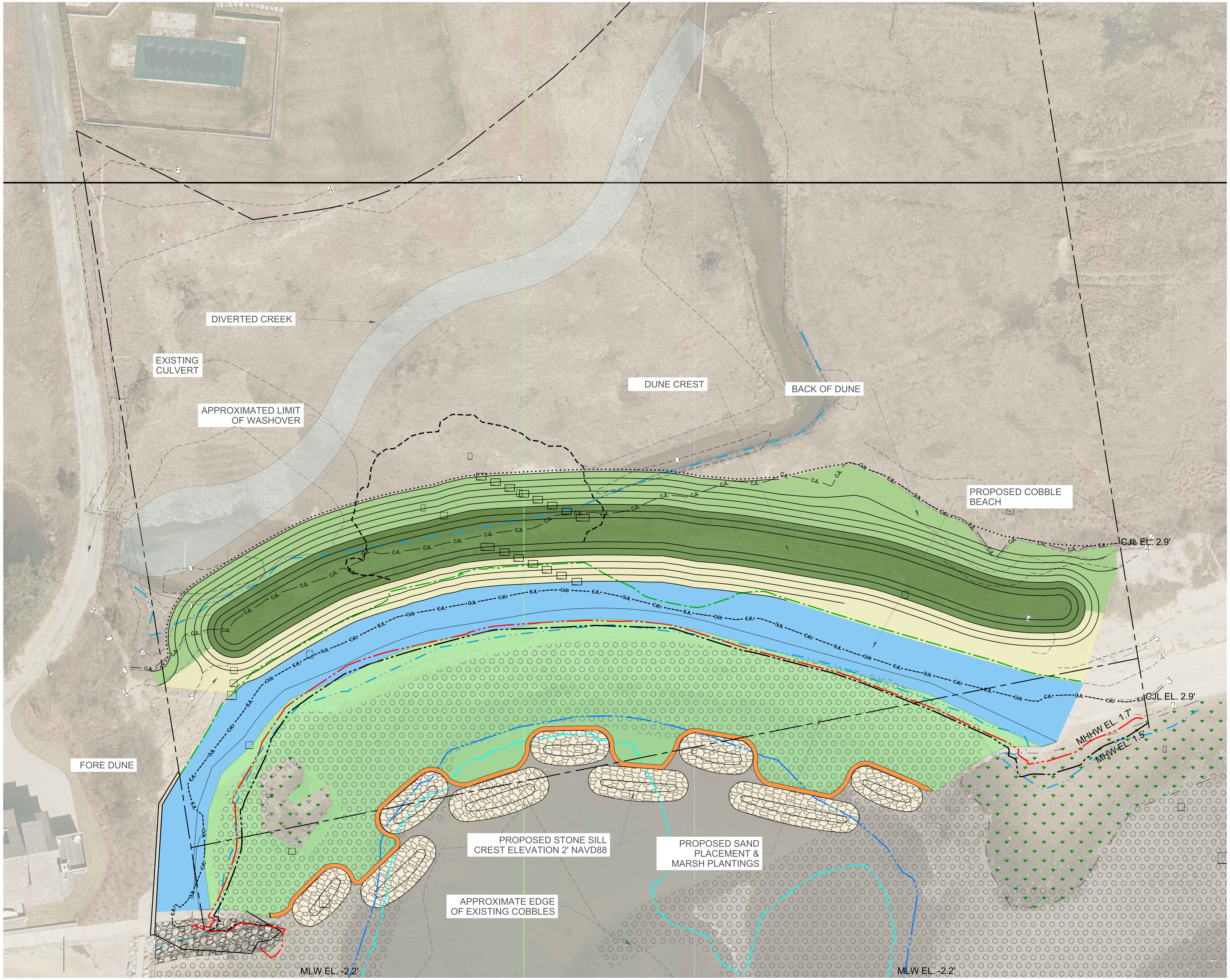
HEPBURN PRESERVE LIVING SHORELINE PROJECT
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

ALTERNATIVE 4
DUNE RESTORATION WITH STONE CORE, COBBLE BEACH
SAND PLACEMENT, MARSH PLANTINGS, MARSH SILL (+2.0')

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: HM	REVIEWED BY: DCS	CHECKED BY: DCS	FIGURE 6
DESIGNED BY: HM	DRAWN BY: JJZ	SCALE: AS SHOWN	
DATE: AUGUST, 2019	PROJECT NO. 03.0034368.00	REVISION NO. 0	SHEET NO. 6 OF 8



NOTES:

1. DATUM: CONTOURS AND POINTS REFERENCE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88). HORIZONTAL DATUM REFERENCES NORTH AMERICAN DATUM OF 1983 (NAD83) CONNECTICUT STATE PLANE COORDINATE SYSTEM, US FOOT.
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4. AERIAL IMAGE FROM GOOGLE EARTH, DATED OCTOBER 2016. IMAGE SAVED SEPTEMBER 20, 2017.

LEGEND

- PROPERTY BOUNDARY
- COASTAL JURISDICTION LINE (CJL)
- SNOW FENCE
- EXISTING BREAKWATER
- APPROXIMATE EXTENT OF EXISTING COBBLES
- EXISTING SALT MARSH
- PROPOSED STONE SILL
- COIR LOG MARSH EDGE
- REDISTRIBUTED COBBLE
- PROPOSED SAND PLACEMENT & SALT MARSH PLANTINGS

N
W E
S

0 10' 20' 40' 60'
SCALE IN FEET 1" = 20'

NO.	ISSUE/DESCRIPTION	BY	DATE

HEPBURN PRESERVE LIVING SHORELINE PROJECT
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

ALTERNATIVE 5
DUNE RESTORATION, COBBLE BEACH
SAND PLACEMENT, MARSH PLANTINGS, MARSH SILL (+2.0')

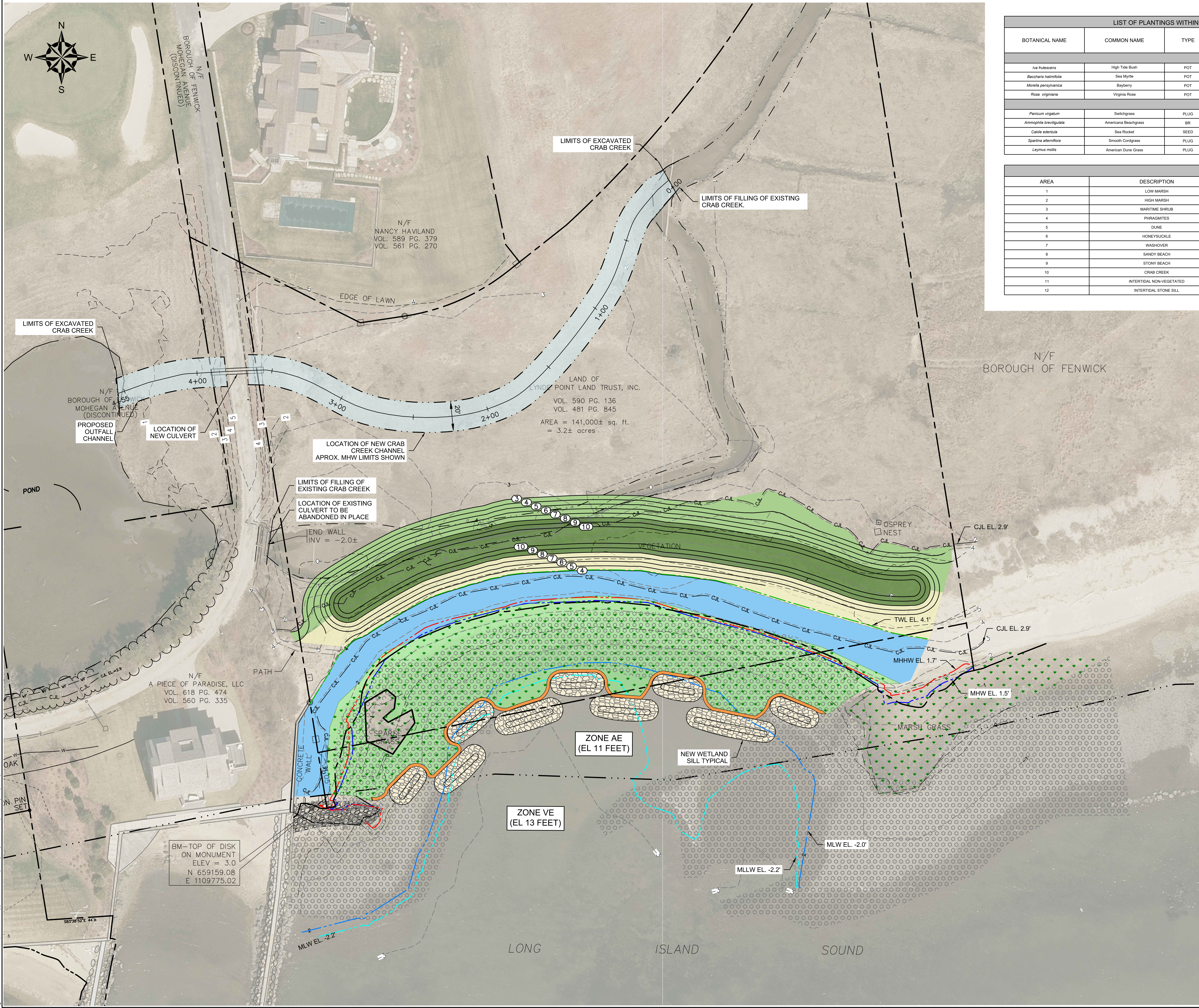
PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: HM	REVIEWED BY: DCS	CHECKED BY: DCS	FIGURE 7
DESIGNED BY: HM	DRAWN BY: GRB	SCALE: AS SHOWN	
DATE: AUGUST, 2019	PROJECT NO. 34368.01	REVISION NO. 0	SHEET NO. 7 OF 8

LIST OF PLANTINGS WITHIN DUNE RESTORATION BY RESOURCE AREA AND ELEVATION								
BOTANICAL NAME	COMMON NAME	TYPE	SIZE	FORE DUNE	TOP DUNE	BACK DUNE	LOW MARSH	MARITIME SHRUBLAND
				EL. 4.0-8.0	EL. 8.0-11.0	EL. 2.0-8.0	EL. 0.0-2.0	EL. 1.0-2.0
SHRUBS								
Iva frutescens	High Tide Bush	POT	2-4'					X
Baccharis halimifolia	Sea Myrtle	POT	2-4'					X
Morella pensylvanica	Bayberry	POT	2-4'			X		
Rosa virginiana	Virginia Rose	POT	2-4'		X	X		
GRASSES AND FORBS								
Panicum virgatum	Switchgrass	PLUG	2"			X		
Ammophila breviligulata	Americana Beachgrass	BR	6"	X	X	X		
Cakile edentula	Sea Rocket	SEED	lbs.			X		
Spartina alterniflora	Smooth Cordgrass	PLUG	6"				X	
Leymus mollis	American Dune Grass	PLUG	6"		X			

HABITAT AREAS CHANGES				
AREA	DESCRIPTION	EXISTING (SF)	PROPOSED (SF)	NET CHANGE (SF)
1	LOW MARSH	42,200	60,040	17,840
2	HIGH MARSH	31,040	38,320	7,280
3	MARITIME SHRUB	44,750	30,100	-14,650
4	PHRAGMITES	4,505	0	-4,505
5	DUNE	20,970	26,070	5,100
6	HONEYSUCKLE	1,210	970	-240
7	WASHOVER	5,920	0	-5,920
8	SANDY BEACH	11,460	1,150	-10,310
9	STONY BEACH	17,060	10,310	-6,750
10	CRAB CREEK	7,150	6,820	-330
11	INTERTIDAL NON-VEGETATED	13,510	0	-13,510
12	INTERTIDAL STONE SILL	0	5,140	5,140



LEGEND

- PROPERTY/STREET LINE
- FLOOD ZONE BOUNDARY FEMA BASE FLOOD ELEVATION (BFE) INDICATED
- EDGE OF STREAM/POND/
- CJL — COASTAL JURISDICTION LINE (CJL)
- WF — WETLAND
- 50-FOOT WETLAND SETBACK
- EXISTING CONTOUR (MAJOR 5 FOOT INTERVAL)
- EXISTING CONTOUR (MINOR 1 FOOT INTERVAL)
- TWL EL. 4.1 — TIDAL WETLAND LIMIT
- MHHW EL. 1.7 — MEAN HIGH HIGH WATER
- MHW EL. 1.5 — MEAN HIGH WATER
- MLW EL. -2.0 — MEAN LOW WATER
- MLLW EL. -2.2 — MEAN LOW LOW WATER
- BRUSH LINE
- D — STORM SEWER/CATCH BASIN
- E — UNDERGROUND ELECTRIC
- T — UNDERGROUND TELEPHONE
- C — UNDERGROUND CABLE TV
- EXISTING BREAKWATER
- APPROXIMATE EXTENT OF EXISTING COBBLES
- EXISTING SALT MARSH IN LIS
- PROPOSED STONE SILL
- COIR LOG MARSH EDGE
- REDISTRIBUTED COBBLE BEACH
- PROPOSED SAND PLACEMENT & SALT MARSH PLANTINGS

0 15' 30' 60' 90'
SCALE IN FEET 1" = 30'

NO.	ISSUE/DESCRIPTION	BY	DATE

HEPBURN PRESERVE LIVING SHORELINE PROJECT
LYNDE POINT LAND TRUST, INC.
OLD SAYBROOK, CONNECTICUT

ALTERNATIVE 6, DUNE RESTORATION, COBBLE BEACH SAND REPLACEMENT, MARSH PLANTINGS, MARSH SILL (±2.0'), CULVERT REPLACEMENT

PREPARED BY:
GZA GeoEnvironmental, Inc.
Engineers and Scientists
www.gza.com

PREPARED FOR:
BOROUGH OF FENWICK
OLD SAYBROOK, CONNECTICUT

PROJ MGR: HM	REVIEWED BY: DCS	CHECKED BY: DCS	FIGURE 8
DESIGNED BY: HM	DRAWN BY: GRB/LDT	SCALE: AS SHOWN	
DATE: AUGUST, 2019	PROJECT NO. 34368.01	REVISION NO. 0	SHEET NO. 8 OF 8

Appendix J – Project Monitoring Plan

Living Shoreline Monitoring Plan
Hepburn Dune and Marsh Preservation Living Shoreline Project

The following Living Shoreline Monitoring Plan presents the recommended methods and practices for Hepburn Dune and Marsh Living Shoreline Project monitoring. This plan was prepared by GZA GeoEnvironmental, Inc. on behalf of the Borough of Fenwick, the project lead.

Site

The project site is a 450-linear foot segment of coastline on the Long Island Sound in the Borough of Fenwick in Old Saybrook, Connecticut. The project site consists of a short, narrow barrier spit that separates the Sound from Lynde Point Marsh, a restored tidal marsh.

Figure 1. Project Location

Dates Active

Five (5) years from the start of construction

Project Lead

Borough of Fenwick
Old Saybrook, Connecticut

Point of Contact:

Ms. Marilyn Ozols
Borough of Fenwick
580 Maple Avenue, P.O. Box 126
Old Saybrook, CT 06471-3001

Living Shoreline Monitoring Plan
Hepburn Dune and Marsh Preservation Living Shoreline Project

Partners

Connecticut Institute for Resilience & Climate Adaptation (CIRCA)
University of Connecticut
Avery Point Campus
1080 Shennecossett Road
Groton, Connecticut 06340

Project Design Team:

Point of Contact: Daniel Stapleton, P.E.

GZA GeoEnvironmental, Inc.
95 Glastonbury Boulevard
Glastonbury, Connecticut

Monitoring Plan Design Team:

Point of Contact: Daniel Stapleton, P.E.

GZA GeoEnvironmental, Inc.
95 Glastonbury Boulevard
Glastonbury, Connecticut

Monitoring Implementation Team:

Point of Contact: Steve Lecco

GZA GeoEnvironmental, Inc.
95 Glastonbury Boulevard
Glastonbury, Connecticut

Project Type

Living Shoreline (see GZA design drawings)
Project Components include:

1. Relocation of a portion of Crab Creek involving: a) installation of a new culvert (with a bottomless arch culvert); b) excavation of new tidal channel; c) removal of the temporary corrugated pipe placed by the DEEP; and d) backfill of the former section of re-aligned channel (using the excavation backfill).
2. Beach nourishment and planting to construct a new dune that is wider and higher than the former dune, but will be consistent with the more robust dunes abutting the project site to the east.
3. Construction of new rock sills placed on an offset, staggered layout with a cuspate alignment consistent with the current project shoreline shape. The purposes of the rock sills are to: a) stabilize the seaward margin of the new Living Shoreline marsh; b) attenuate wave energy during prevailing wave conditions, to support mash survivability; and c) within practical and cost limitations, attenuate wave energy during coastal storm events to minimize the amount of marsh stem breakage (and to a lesser extent, minimize dune erosion).

4. Relocation of existing cobbles within the intertidal zone (within areas to be filled to create new marsh) and placement of these cobbles within the beach. (The existing beach has a high cobble content. The goal is to enhance the existing beach as a cobble beach).
5. Placement of sand fill within the intertidal zone (to the rock sills), with marsh planting to create a new Living Shoreline marsh.

Only components 2 through 5 are included in the monitoring program.

Project Drivers, Goal(s) and Objectives

The goal of the project is stabilize the shoreline and mitigate the potential for a breach of the barrier spit using a Living Shoreline approach as defined by the State of Connecticut.

Chronic and episodic erosive shoreline change has been an on-going issue at the project site. The Borough has expended significant effort and cost to restore the tidal marsh and stabilize the shoreline during the last 10 to 15 years. Shoreline erosion, however, continues. The proximity of the eroded shoreline, which is now close to the tidal marsh and Crab Creek increases the likelihood that the remaining sand spit will be breached during future coastal storms.

Drivers: The observed short term (1983 to 2006) erosive shoreline change with the project shoreline is about from -0.6 meter per year (2 feet per year). Dune erosion. Possible breach of barrier spit.

Goal(s): While a risk-based design basis was not explicitly developed for this project, certain performance goals were established for guidance informing design of the project elements, including the following. These goals provide a general basis for evaluating the project performance during prevailing conditions and coastal storm conditions.

- Survivability of the new Living Shoreline marsh under conditions associated with floods with a recurrence interval of 10-years or less (that is, floods with an annual recurrence interval greater than 10 years may significantly damage the new marsh).
- Minimal beach erosion under conditions associated with floods with a recurrence interval of 5-year recurrence interval or less (that is, floods with an annual recurrence interval greater than 5 years may significantly erode the beach).
- Minimal dune erosion under conditions associated with floods with a recurrence interval of 5-years (that is, floods with an annual recurrence interval greater than 5-years may significantly erode the dune).
- Reduction of the likelihood of a barrier spit breach, at least to the conditions associated with floods with a recurrence interval of 20-years or less (that is, floods with a recurrence interval greater than 20 years may result in a breach).
- Reduction of the observed, on-going shoreline erosion rates at the project site.
- Avoid negative impacts, such as increased erosion and/or shoreline change, in areas outside of the project site.

Objectives: Project performance objectives include: 1) condition of rock sill; 2) condition of marsh vegetation; 3) elevation and condition of cobble beach; 4) elevation and location (total geometry) of dune; and 5) condition of dune vegetation.

Not included in monitoring program:

- Water quality
- Wildlife
- Fisheries

Wildlife is not included in the project monitoring, but may be coordinated with agencies, Lynde Point Marsh and Borough personnel currently performing habitat and wildlife monitoring.

Specific objectives used for monitoring:

- Condition of Rock Sill: <10% damage as defined by rock displacement, loss of geometry, rock displacement into sill gaps and settlement of sill crest, scour/erosion at base

- Marsh vegetation: initial establishment of marsh; 85% vegetation survival by area, including stem breakage, uprooting and /or die-off; natural recovery from post-storm damage; <5% invasive species by area; marsh mudline elevation

- Cobble Beach: maintain elevation (+/- 1 vertical foot) at MHW line; 50% of initial surface cobble coverage

- Dune: maintain dune crest elevation, toe of dune and sand volume (85% of constructed)

- Dune Vegetation: initial establishment of dune vegetation; 85% vegetation survival by area; natural recovery from post-storm damage; <5% invasive species by area

Monitoring Tasks

Monitoring tasks include:

1. Baseline Monitoring: Collection of data prior to the installation of the project, representing baseline topographical, surface coverage and habitat conditions against which future data will be compared. Baseline monitoring has been completed and is presented on the “Existing Conditions Plans” in the project plan set.
2. As-Built Survey: This monitoring ensures that the project was constructed according to design specifications. As-Built survey and drawings will be developed by the contractor upon the completion of the work.
3. Performance Monitoring: Monitoring of change of project components (described above) for the 5-year planned monitoring program.
4. Metocean data documentation over the 5-year planned monitoring program.

Table 1 Monitoring Metric Table

Objective	Metric	Methods	Temporal Resolution	Spatial Resolution	Performance Question	Analysis Method
Rock Sill	Damage	Stone displacement	• Annual: June, October • Post-Storm	Approx. based on visual observation at low tide	Have the sills been impacted	Visual Observation; Photo-documentation
Marsh Vegetation	Vegetation loss by area	Percentage of vegetation loss by area; mudline elevation	• Monthly post-construction for 3 months (visual only) • Annual: June, October • Post-Storm	500 s.f. measuring stations (+/- 15 points)	Is marsh vegetation established; surviving post storm; surviving predation. Is the mudline eroding or accreting.	Visual observation; Photo-documentation; Differential GPS
Cobble Beach	Beach elevation at MHW; cobble coverage	Elevation change; Cobble density (approximate)	Annual: June, October Post-Storm	3 cross transects and 1 longitudinal transect at MHW	Is the beach profile maintained seasonally and post-storm	Visual observation; Photo-documentation; Differential GPS
Dune	Dune profile; crest elevation	Profile change; overwash	• Monthly post-construction for 3 months (visual only) • Annual: June, October • Post-Storm	3 cross transects	Is the dune profile maintained seasonally and post-storm; Is there significant post-storm overwash	Visual observation; Photo-documentation; Differential GPS
Dune Vegetation	Vegetation loss by area	Percentage of vegetation loss by area	• Monthly post-construction for 3 months (visual only) • Annual: June, October • Post-Storm	500 s.f. measuring stations	Is marsh vegetation established; surviving post storm; surviving predation.	Visual observation; Photo-documentation

Sampling Frame

The limits of monitoring are defines as the Limits of Work presented on sheet "Erosion and Sedimentation Control Plan – Living Shoreline Work" of the project plans.

Sampling Design Type and Spatial Resolution

Monitoring measurement location coordinates: Connecticut State Plane coordinates and latitude/longitude

Analysis Methodology

The analysis methodology includes:

- Photo-documentation using pre-established fixed station points and view (for time-stepped documentation)
- Survey documentation (using pre-established fixed stations and lat/long and state plane coordinates)
- Metocean data documentation using NOAA tide station (water levels) and New London Airport (waves) and NOAA Buoy (waves)

- Change analysis:
    - Vegetation by area
    - Elevation in feet to 0.3 foot (+/-) vertical resolution; NAVD88 datum
    - Transect profile: elevation (see above); horizontal: lat/long and state plane coordinate system
    - Cobble content: visual approximation of surface coverage per representative 500 s.f. sample areas
- Correlation: qualitative and quantitative (when practical) correlation between project component change and metocean data (specifically temporal trends and storm specific)

Documentation

Post-monitoring report; final summary report; ESRI ArcGIS layers

Maintenance and Adaptive Management

Maintenance and adaptive management is not a project requirement but may be performed at the discretion of the project owner. Maintenance activities, if performed during the 5-year monitoring program, will be documented in the monitoring reports.

GZA GeoEnvironmental, Inc.